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AIR-TO-GROUND TARGET ACQUISITION SOURCE BOOK: A REVIEW OF THE LITERATURE

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ORLANDO, FLORIDA

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The properties of the visual system, including Human MTF are described. Ground target environmental factors, including Target/Background variables, and Atmospheric conditions are related to Target Acquisition by direct visual search and through imaging systems. Imaging systems parameters are described. Prediction and evaluation of Target Acquisition through modeling and simulation are discussed. Areas for further Target Acquisition work are recommended. A Bibliography of more than 1750 entries is accompanied by Tables which key the entries to Target Acquisition parameters and variables.

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FOREWORD

The preparation of this source book was a joint effort of a number of dedicated people, and reflects the technical judgements of many persons, most of whom have been given due credit, it is hoped. Certain sources have been relied on so heavily that their authors must be given special recognition.

The foremost of these contributors is Ronald A. Erickson, Naval Weapons Center, China Lake, California. Not only is his work quoted extensively throughout the book, but also his detailed and expert review of the major chapters of the book was invaluable in sharpening and focusing the material.

Dr. Charles P. Greening, Autonetics Division, Rockwell International, Anaheim, California, is responsible for much of the modeling work reported in Chapter Six. Dr. Harry P. Snyder, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, furnished valuable assistance and performed a detailed review of Chapter Four. Dr. William D. Bliss, Montana State College, Bozeman, Montana, reviewed and commented on the first six chapters. Ms. Kathryn L. Cromer provided bibliographic research in the development of the initial materials.

The Conversion Factors Tables in Chapter Two are reproduced with permission from Eastman Kodak Company. The figures on atmospheric illuminance, transmittance, and attenuation are reproduced with permission from RCA Corporation; copyright proprietor of the RCA Electro-Optics Handbook, 1968 edition.

Finally, it is appropriate to acknowledge the expertise and competent guidance furnished by Drs. John J. O'Hare and Martin A. Tolcott of the Office of Naval Research.

September, 1974
Orlando, Florida

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CHAPTER ONE

INTRODUCTION

1.1 The Problem

A variety of military missions rely on the ability of an airborne observer to detect and identify ground objects as possible targets for weapons carried by aircraft or launched from ground sites. These missions include the close air support of ground troops, interdiction of roads and rivers, search and destroy missions, and reconnaissance, surveillance, and intelligence-gathering missions. These missions are flown in a variety of aircraft, under a variety of weather and atmospheric conditions, and with a variety of sensors and aids available to the observer. All these missions have one thing in common; they rely on the ability of the human eye/brain combination as the initiator of the sequence of events which leads either to a successful or unsuccessful mission. In mobile targets, real-time or near real-time target acquisition missions are required because the information is of less value if not immediately used.

Although automatic target detection methods are being actively pursued which may possibly supplant the human observer in this important task, no feasible method has been developed which has the combined flexibility, programmability, quick response, ability to reject clutter, resolution, ability to respond to small contrast, ability to adjust to low and high ambient illumination (dynamic range), shape and contour matching ability, ability to detect anomalies in the scenic content, and ability to detect movement and changes as the human observer. Small weight and volume make the human observer a very effective sensor and data analyzer. Because the visual scene is continually changing, and a large number of variables affect the probability of detecting and identifying targets, it may never be possible to completely automate the target acquisition process. The difficulty and costs associated with automating target detection/identification make it necessary to optimize the sensor and processor of information. The best possible display is needed to provide cueing and navigational aids, and reduction of false targets (clutter) in the scene. This requires the best of sensors, and sometimes even the changing of system or mission parameters.

Since World War II, steady interest has been shown in the target acquisition process in the Armed Forces and in the research and development establishment. During the early days of World War II, the Armed Forces Vision Committee was established. Their early work was motivated by the Anti-Aircraft Artillery (AAA) requirement for ground observers to search for low altitude targets while airborne observers visually searched

the sea or ground for targets. Recent renewed interest in target acquisition has resulted from the development of surface-to-air missiles (SAM's), radar directed accurate AAA, and recent tactical operations in jungle and low visibility environments. The new types of sensors such as Forward Looking Infrared Systems (FLIR) and Low Light Level TV have also increased the use of displays such as cathode ray tubes in target acquisition.

A recent symposium on target acquisition concluded that "the state-of-the-art in missile design and guidance systems has far outstripped the ability of the human operator to acquire ground targets at maximum launch ranges" (Payne, 1972). Modern weapon capabilities make it imperative that targets be detected and identified while the aircraft is still far enough outside the enemy's defensive capability to launch its weapon (or designate it to a weapon system) and leave the area fast. Launch and leave weapon systems are being designed which will help the pilot/observer do this effectively. The limiting factor in all these systems is still the initial target detect/recognize task. Figure 1-1 (taken from Payne, 1972) illustrates the problem in terms of slant range. Experience in both operations and in flight testing indicates that under ideal conditions, far less than 100 percent of available targets are usually detected. The figure is reduced considerably when conditions are not ideal, i.e., when camouflage, terrain masking, and low level, high speed search is involved. When long slant range requirements are added, the success figure is decreased proportionately. The operator reaction time requirements in designating the target have produced system problems. Some proposed airborne systems have had to be abandoned because they were shown to be unfeasible by timeline analysis.

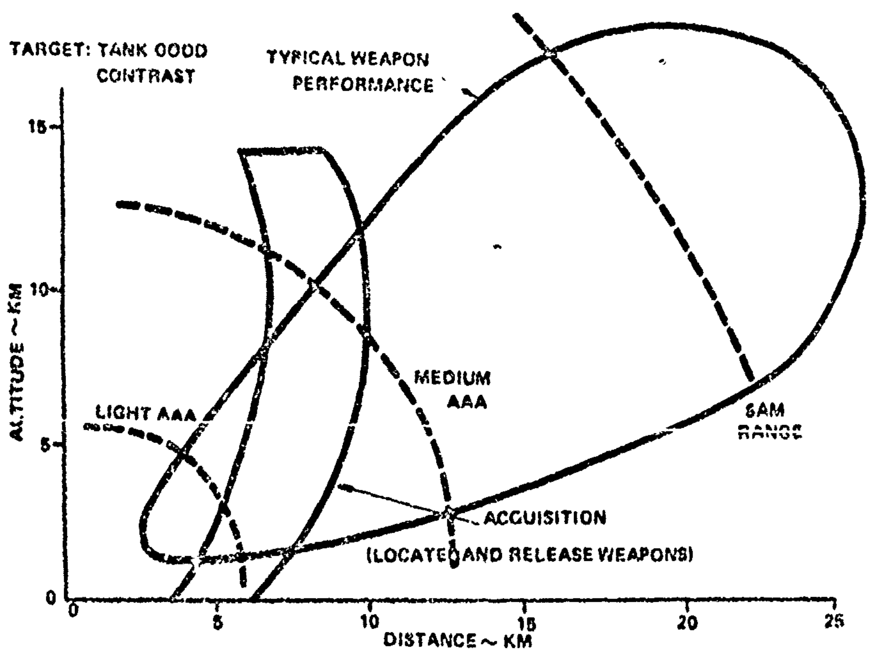

Figure 1-1. Weapon Capability versus Sensor Capability

There are several ways in which this operational time/range problem may be solved or mitigated.

1. The detection/recognition system may be optimized to make better use of the operator's visual capability. This may be done by using sensors better tuned to the environment/target signature or by combining sensors to enhance the target and hence its detectability.

2. Target cueing can be used to eliminate false targets and take advantage of known facts about the target. Other types of systems such as radar and navigational gear can also be used to cue the target or target area.

3. Particular operational missions can be designed to maximize the probability of target acquisition if the capability of the human observer in different operational environments is known in combination with the capability of the system available to do the job.

4. Observers can be selected and trained to better use the capability of the systems with which they have to work.

5. The display used by the observer can be optimized in image quality (resolution, contrast rendition, and signal/noise ratio) to give the best possible information and data needed for the target acquisition task. Display size, viewing distance, system magnification, gain, polarity, and contrast settings should be matched to human visual requirements to take advantage of human spatial and temporal integration and discrimination capability. If a raster scan display is used, scan rates, interlace, sampling rates, and other TV parameters can be optimized to improve the display visually.

It can thus be seen that target acquisition capability depends for the most part on:

1. Environmental and mission-related factors; mission requirements, terrain, weather, weapon capabilities.

2. Hardware and equipment related factors; data processing, cueing, display, designation, instrumentation, etc.

3. Human Factors; training and selection, visual response capability and requirements, compatibility, and interfacing, cognitive aspects.

All these factors affect target acquisition performance. Although considerable work has been done in each of the above areas, there is a continuing need to organize and integrate the data into a form which is meaningful to a system designer, to operations or mission planners, and

to basic or applied researchers in each of the areas. This need exists due to the breadth of technology and the large number of professional disciplines involved in target acquisition. Technology in this area is moving so fast that comprehensive reviews often are obsolete soon after publication.

There is also need for an organization of specialists in the target acquisition area. In the recent past, the Infra-Red Information Symposium (IRIS) has provided a clearing house for target acquisition data with emphasis on IR technology. The classified nature of the IRIS meetings has limited membership and attendance at the specialty group meetings. The formation of a Department of Defense Target Acquisition Working Group (TAWG) has the promise of providing increased impetus to the application of research and analysis of target acquisition by encouraging standardization of nomenclature and measurement techniques, and by recommending government funding of critical work needed.

1.2 Boundaries of This Source Book

Target acquisition technology is too broad to be adequately covered by one document and provide maximum utility to the wide range of concerned personnel. This source book is primarily intended to cover the following aspects of target acquisition to the depth required:

1. Air-to-ground target acquisition only. Consideration of space and time makes it necessary to exclude ground-to-air from discussion, as well as ground-to-ground and air-to-air acquisition problems. However, due to the similarities among these areas, the reader may wish to generalize to those cases. He is cautioned to do this with the requisite safeguards for such an extension.

2. Real-time target acquisition is the primary concern although target acquisition by means of photographic or near real-time systems or otherwise related recorded imagery is involved peripherally. The photographic target acquisition area is a separate problem and involves some other sets of independent and dependent variables.

3. Target acquisition using direct visual and real-time electro-optical (E-O) target acquisition systems is addressed by way of the display. Real-time E-O is defined here as television or forward-looking infrared (FLIR) generic type systems. No attempt is made to discuss target acquisition by means of non-imaging radar, sonar, or other types of devices.

4. The human factors aspects of target acquisition are stressed. Although the man-machine interface in target acquisition is not precisely defined, and there may be some controversy as to what constitutes "Human Factors Aspects," the subject is

discussed as completely and thoroughly as possible. For the purposes of this book, Human Factors Aspects are defined as those which involve human vision ultimately, as mediated by the display parameters, viewing conditions, exposure time, level of briefing and cueing, and decision related parameters, and involve contrast or form discrimination thresholds. Those parameters that are primarily system or sensor related are not covered in detail, except where they impact the human in the system.

5. Although some important classified papers on target acquisition have been reviewed and are referenced in the source book, to keep this book unclassified and therefore maximally available, classified material has been excluded. The bibliography, however, does include references to pertinent classified literature.

6. The emphasis in the book has been on the data of basic and applied research rather than on strictly applied work (related to a particular system or aircraft and hence of limited generality).

The decisions to include and exclude material were made after careful study and evaluation. All too often no two results of similar experiments are ever quite the same. The best one can hope to obtain from this tangle of data are rules which guide inquiry in the most fruitful direction.

The target acquisition problem might also include research in target tracking, alignment, and inputting devices on the motor side of acquisition. Obviously, these variables interact to an unknown degree and in an unknown manner with the visual part of the target acquisition problem. At the present time, including response variables in target acquisition results in a basically new target acquisition situation whose effects on the dependent variables of detection/recognition range and probability of detection/recognition are basically unknown and unpredictable. When other complicating factors such as differences in types of sensors, measurement techniques, and operational conditions are added, the problem is further compounded.

The major purposes of this source book are to start the process of sorting out and to preliminarily evaluate the variables and their relative importance to the search and acquisition process, to organize them meaningfully, to make evaluation judgements where required, and to indicate where data are available, where information is lacking and where experimentation can make the most efficient payoff by significantly reducing our ignorance. It is hoped thereby to provide a data source for systems and design engineers involved in target acquisition design problems.

1.3 Definitions of Key Terms

The majority of real-time air-to-ground target acquisition missions are those involving combat air support. Thus, the acquisition of tactical-type targets is emphasized. A clear definition of terms is necessary in

discussing these missions. The Glossary is a preliminary attempt to obtain a standardized group of definitions which are acceptable to specialists and users alike, and to indicate how these terms will be used in this source book. Where possible the United States Department of Defense Definition of Military Terms has been followed. But only a small number of the key terms were found to be applicable.

The target acquisition research area suffers from a lack of common and agreed upon definitions of terms. No one has stated the case better than Bliss (1965):

> "The three most commonly used and confused terms employed to describe the visual problems of targeting are detection, recognition, and identification. In general, they refer to progressive refinements of target acquisition. Detection is the determination that some object is present at a location compatible with its being the target; recognition is the determination that the detected object is a member of that subclass of objects for which the observer is looking (tanks, trucks, ships, four-engined aircraft, or whatever); and identification is the determination of which member the target is of the subclass of interest.
>
> "In this report, target acquisition is used as a generic term to cover any or all aspects of targeting. Target acquisition is thus a neutral term in that it can mean detection, recognition, identification, or whatever problem of targeting the test or experiment is concerned with. If the target problem which a system has to solve in order to work successfully is only target detection, then the system has acquired its target when it has detected it; if the system cannot go into operation until it has been provided the serial number of the target, then it has not acquired its target until it has identified it.
>
> "In military operations, the problem of visual acquisition of ground targets is actually five different problems, one for each of five different missions: (1) reconnaissance or surveillance, (2) navigation, (3) attack on targets of opportunity, (4) attack on targets identified in prebriefing, and (5) vectored attack with no search or limited search required. Each of these five missions presents a target acquisition problem different from each of the others.
>
> "For a given target in a particular background at a particular hour on a specific day (and all other things being equal), there is no reason to expect the same target acquisition ranges for any two of these five missions. Therefore, to be meaningful a discussion of target acquisition (detection, recognition, identification, or whatever) must

be prefaced by a specification of the mission, and consideration of the significance of target acquisition ranges or probabilities should be restricted to a particular mission. In the studies conducted, this has almost never been done, and the fact that it has almost never been done is one of the important sources of error in the design, conduct, and interpretation of experiments and flight tests in this field.

"Four of the five missions described above require preacquisition search. A tremendous complication is added to the relatively simple problems of detection and recognition by the requirement of searching for the target in a moving visual field, but only a fraction of the tests and experiments include search of a moving visual field as part of the task.

"A final consideration of importance in the interpretation of target acquisition work which is frequently not treated explicitly in reports is the relationship between what the observer was looking for and what he actually saw -- i.e., the correspondence between expectation and reality. All sorts of elements go into making up the observer's expectations -- prior experience with the type of mission or experiment, familiarity with the particular stimulus material (terrain), nature of the task (reconnaissance versus attack; detection versus identification), type and specificity of briefing (instructions; set), etc. The precise degree and kind of similarity between expectation and actuality make a very great difference in probability and range of acquisition. The foregoing considerations concern the adequacy of the test design in the sense of whether the test or experiment is designed to shed light on the actual problem of interest or on some more or less remotely related problem -- whose degree of remoteness may not be recognized by the experimenter.

"An additional difficulty in target acquisition work is that the term "target" is not specifiable in an objective way. A target is anything that anybody is interested in finding and doing something about. It may have no visual representation (an underground bunker); it may have an ambiguous representation (a command post or headquarters); it may have a visual representation which changes drastically with the aspect from which it is viewed (a tank) or the altitude from which it is viewed (a radio tower) or the presence or absence of sun and glint (a polished aircraft fuselage); etc. This ambiguity does not prevent meaningful work on specific targets, but it suggests that an all-inclusive solution to the problem of visual target acquisition is unlikely." (pp. 3-5).

In this source book, the following key definitions will describe the target acquisition process:

	Perceptual Definition	Operational Definition
Observer:	The individual who is acquiring targets.	The pilot, or an assigned observer, either one, depending upon the aircraft type and the task required.
Target:	The object class for which visual search is conducted.	The assigned military object (prebriefed) or class of objects of a certain type.
Detection:	The observer decides an object present in his field of view should be inspecteo further (e.g., man-made object). Object may have been visible before detection, but was not distinguishable enough from other objects to cause inspection decision.	The observer inspects the object; observer takes whatever action is necessary to further inspect object; e.g., slew TV, zoom the FOV, look at object with eye.
Recognition:	The observer decides the object belongs to a particular class of objects (e.g., vehicle). There are hierarchies of class names; the particular hierarchy for recognition decision is determined by scenario and prebriefing.	The observer begins an attack mode. Attack mode includes designating target to fire control system, flying aircraft as required (fly over or by target), armament switching (e.g., master arm on), etc.
Identification:	Observer decides ob'ect is in particular subclass within class (e.g., tank). The subclasses are dependent upon classes, scenario, and prebriefing.	Observer continues attack and commits weapon release.

The definition of "detection" is a departure from a classical definition: the awareness of the presence of an object. The classical definition might be equated to "psychophysically visible." The visual field i usually full of visible objects; the fact that they can be sensed is a necessary, but not sufficient, condition for taking action. The definitions given in the table are action-oriented and could be measured in a real-world situation (simulated or operational).

The term "class" of objects is intentionally left in general terms, since -- although the operational definition always holds (the action taken is the same) -- class hierarchies can change with changes in scenario, mission, briefing, and tactics.

1.4 State-of-the-Art of Target Acquisition

Although it is a truism to say that the target acquisition process is very complex, the statement bears repetition. Understanding this complexity requires a knowledge of the basic and applied disciplines involved. The target to the observer link involves:

1. The basic physics of the electromagnetic spectrum, especially in the visual portion

2. The radiant energy properties of the scene being viewed

3. The geometry of the viewed scene

4. The characteristics of the sensing and display system

5. The capabilities and limitations of the human visual system

6. The cognitive processes of the observer

7. The operational capabilities of aircraft.

Good research in air-to-ground target acquisition requires an applied physics-meteorological-electronic-physiological psychologist, trained as a pilot and with a broad experience in military operations. This unlikely combination is hard to find. Those who are well experienced in one or more facets of the problem are likely to emphasize their area of interest and to overlook the equally complex problems in other pertinent areas. Middleton (1952) in discussing the interdisciplinary knowledge needed for an understanding of vision through the atmosphere stated "...at the present time a worker in the field of vision through the atmosphere is as likely to be a physiologist or a psychologist as a meteorologist or a physicist. For the subject straddles the diffuse border between psychology and physics, and is in consequence regarded with mistrust by the sterner immigration officers of both domains. To the guardians of physics it is not a very desirable visitor because its purse is not very well filled with significant figures, and to the psychological inspectors it seems to have a formidable array of mysterious symbols on its passport..." (p.3).

Add to this list the design engineers who expect to find clear design criteria for a target acquisition system, and the military commander who fails to understand why his pilots are unable to locate

the target with more precision. It seems incongruous to each specialist of his own field that air-to-ground target acquisition is not yet a fine art after 60 years of research and development.

1.5 Study Findings

To compile this source book, the available open literature in the area of target acquisition was reviewed, integrated, and evaluated; available data were collated and compared; differences among applied and research oriented data, methodology, and objectives were assessed and evaluated; and the applicability of all available data was applied to goals and purposes. As a result of this study, it was concluded that:

1. The target acquisition literature is voluminous. This is demonstrated by the size of the bibliography included in this source book; over 1700 articles, books and reports are cited.

2. The target acquisition area is interdisciplinary as demonstrated by the number of different journals in which target acquisition reports are published and the disparate background of the authors.

3. The target acquisition area is not well defined conceptually, experimentally, or in terms of recognized and standardized terminology. It contains many mixed and overlapping concepts and definitions. This is certainly due to its interdisciplinary nature, to differing emphases and purposes, and to the lack of an authoritative or evaluative organization to establish standards.

4. The target acquisition area is "messy" because of the large number of ill-defined and inadequately understood variables involved, and because of the many interactive effects among the critical variables.

5. Theory construction has primarily been limited to the mathematical modeling of the target acquisition process with few validation studies and testing of sub-models.

6. Security considerations have limited the interchanges of data because many of the critical articles are classified. Proprietary classification has also limited the distribution of data and critical reports.

7. There is a gulf between basic research data availability and applicability and operational data requirements of system designers. Target acquisition problems are complex and difficult and this may be one reason for the lack of data applicable to applied problems.

8. Target acquisition problems have no simple answers, only indicators of possible solutions. Popular concepts such as visual lobe, image quality, MTFA, SNRD, contrast ratios, and resolution lines across the target have attracted enthusiastic supporters as an exploratory or summative concept only to be supplanted by another one sooner or later. Each has been found to be only part of the answer. No one concept can yet provide final and definitive predictive results. This is to be expected considering the complexity of the field. No simple solution exists and each new concept should be accepted tentatively, expecting it to be ultimately replaced by a better idea.

It is hoped that the reader will find this book useful, both in those parts of it which concern his work and needs as well as in related areas, and that he will draw his own conclusions about state-of-the-art of target acquisition. Readers' comments, criticisms, and evaluations are invited.

1.6 How to Use This Book

This book has been organized along traditional target acquisition natural lines of fracture, i.e., functional lines. There are separate chapters on the human visual system, target and environmental factors, sensing and display systems, search skills, mathematical modeling, and the MTF approach to target acquisition. The Table of Contents and the Tables of Target Acquisition Variables accompanying the Bibliography provide the tools with which users can find particular data and/or subjects of interest.

Every attempt has been made to include useful accepted data and to organize them for maximum usefulness and applicability, whether the work consists of basic research data, applied or flight test data, or is analytic in nature. In screening the studies, it is possible that excellent studies were not included through oversight or lack of time and availability. It is also possible that studies not up to acceptable standards were inadvertently included. The complex process of acquiring targets involves the control of many variables. The complexity may be readily appreciated by considering the lists of pertinent factors suggested by various investigators. Gottsdanker (1960) lists nine general search-determinants, the majority of which are visual factors. Bloomfield (1970) expands upon Gottsdanker to develop an exhaustive list of laboratory studies related to visual search. Addressing the air-to-ground target acquisition problem, Greening and Snyder (1967) list 12 general target and environmental variables or factors and 9 observer and dynamic variables. Franklin and Whittenburg (1965) classified 24 variables as important for target acquisition in 7 major classifications. Table 1-I presents the general headings and sub-factors noted as important by each of the investigators cited above. Figure 1-2 notes the various elements in the target acquisition process included in this Source Book; under each major element are variables that are significant to some degree in the target acquisition process.

TABLE 1-I

Key Variables Cited in Visual Search and Target Acquisition

LABORATORY RESEARCH DATA (VISUAL SEARCH EXPERIMENTS)

Gottsdanker (1969):

<u>Search Determinants</u>
- Competition
- Embeddedness
- Smallness
- Distortion
- Interposition
- Search Goals
- Search Aids
- Search Strategies

Bloomfield (1970):

<u>Search Determinants</u>
- Competition
- Camouflage
- Threshold Contrast
- Relative Target Size
- Target Orientation
- Distortion
- Obstruction

<u>Observer Variables</u>
- Eyesight
- Experience
- Motivation
- Age

<u>Task Variables</u>
- Movement
- Optical Environment
- Type Search Trials
- Target Specification
- Search Area and Aids
- Time Limits
- Search Measures

SIMULATOR DATA (TARGET ACQUISITION STUDIES)

Greening & Snyder (1967):

<u>Target Characteristics</u>
- Contrast
- Target Size
- Target Shape
- Target Motion

<u>Luminance Effects</u>
- Level Illumination & Reflectance
- Directional Effects
- Chromaticity

<u>Terrain & Background Effects</u>
- Texture & Pattern
- Terrain Irregularity
- Vegetative & Structural Masking

<u>Atmospheric Effects</u>

<u>Static Geometry</u>
- Altitude
- Range
- Lateral Offset

<u>Dynamic Effects</u>

<u>Observer Variables</u>
- Observer Characteristics
- Briefing
- Training
- Cognitive Effects
- Task Loading

FIELD TEST DATA

Franklin & Whittenburg (1965):

<u>Target Variables</u>
- Size
- Shape
- Luminance

<u>Target/Ground Variables</u>
- Contrast
- Clutter
- Density

<u>Environment Variables</u>
- Illumination
- Sun Angle
- Visibility
- Sky/Ground Ratio
- Terrain
- Vegetation

<u>Aircraft Variables</u>
- Altitude
- Range
- Speed
- Approach Angle

<u>Observer Variables</u>
- Visual Skills
- Training, Experience

<u>Task Variables</u>
- Search & Scan Technique
- Knowledge Target Location

<u>Secondary Variables</u>
- Apparent Target Motion
- Apparent Target Size
- Apparent Target/Ground Contrast
- Exposure Time

TARGET BACKGROUND PARAMETERS

Type
Size
Shape
Contrast
Color
Luminance-Reflectance
Texture
Motion
Shadow
Terrain Type
Vegetation
Masking
Camouflage
Clutter
Cues

Distinctiveness
Conspicuity
Embeddedness
Ambiguity
Confusability

AIRCRAFT PARAMETERS

Altitude
Range
Speed
Offset
Target Exposure Time
Type Aircraft
Crew Size
Seat Position
Apparent Motion

ENVIRONMENT PARAMETERS

Visibility
Cloud Cover
(Sky-Ground Ratio)
Sun Angle
Illumination Level
Diurnal Variation
Seasonal Variation
Scintillation
Glare
Attenuation
Transmittance
Apparent Contrast
MTF

SENSOR DISPLAY PARAMETERS

Sensor Type
Field of View
Resolution
Contrast Ratio
Gamma
Signal-to-Noise
Frame Rate
Interlace
Integration Time
Pointing Angle

Display Size
Aspect Ratio
Viewing Distance
Displayed Signal-to-Noise

Color
Spot Wobble
Scene Rotation
Display Freeze
Enhancement

OBSERVER PARAMETERS

Fixation
Search Time
Search Pattern
Visual Acuity

Experience
Training
Expectation
Motivation
Task Load
Stress

Number of Observers
Prebriefing
Cueing
Search Aids

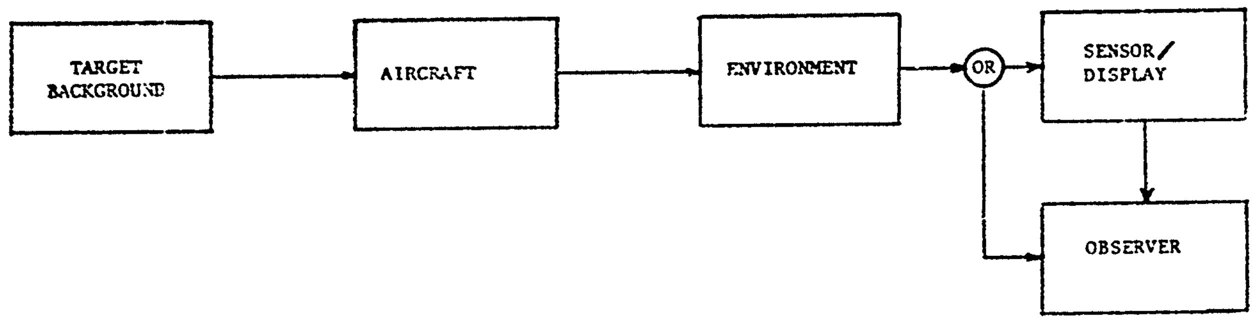

Figure 1-2. Typical Parameters in Air-to-Ground Target Acquisition Process

The chapters are organized around the concepts presented in Figure 1-2. First, Chapter 2 is a brief review of the pertinent properties of the human visual system, basic to any understanding of finding targets. Chapter 3 considers the target-geometry-environment complex in which any visual search for targets is conducted. Chapter 4 evaluates the sensor-display parameters involved in using E-O systems to help acquire targets. Chapter 5 considers the operator as he is involved in visual search for targets. Chapter 6 considers the evaluation of the target acquisition process, i.e., the theoretical models used to predict the real-time simulation models and field testing. Chapter 7 is a summary in the form of design recommendations, operational implications, and research required. A Glossary of Terms with our recommended definitions of those terms is presented. The Bibliography cites more than 1700 related references.

1.7 Conclusion

Chapter 1 has introduced the problem of target acquisition from an operational standpoint, described the basic components of the target acquisition problems, discussed the present state-of-the-art, and noted the areas that follow where more detailed material is presented. A tentative list of the critical variables involved has been presented to indicate the boundaries and limits to the field. The obvious interdisciplinary nature of the data and approaches militates against narrowness of approach and viewpoint. The purposes and goals of the book were discussed with suggestions of how data could be found and used. It is the basic tenet of this book, and it is hoped proven by the evidence provided, that human factors are at the heart of the target acquisition process and that the central determiner of system success is the ultimate dependence on human visual performance. Present day systems depend on human capability to search target areas for targets or target-like spots, discriminate contrast, discriminate form or contour, "see" through noise, visually integrate time and space, remember scene details, and note changes in the observed scenes.

1.8 Summary

This volume is intended as a source book. As much of the available evidence pertaining to the target acquisition process as practicable has been reviewed. An extensive bibliography has been compiled. Many of the references cited in the bibliography as useful sources of data and information have not been reviewed or cited in detail in the discussions of target acquisition data. The approach chosen was to consider pertinent reports or critical research where applicable. Reports or information that provide further detail or corroboration may have been inadvertently omitted or not considered in the text. It thus is possible that some significant research may have been missed. Our search for unifying concepts and for any practical simplification of the problems of finding targets has not been especially fruitful. We thus have prepared a data

source, one place where most sources of information can at least be found. It is hoped that this mass of material will provide cohesive and useful information that will allow designers of target acquisition systems to develop and demonstrate the ultimate air-to-ground target acquisition system. At that point we will propose the preparation of a Target Acquisition Handbook.

CHAPTER TWO

PROPERTIES OF THE HUMAN VISUAL SYSTEM

The purpose of this chapter is to present enough basic information about the functioning of the human visual system to help people from a variety of fields understand how visual capabilities are involved in target acquisition. How the physical stimulus of light interacts with the eye will be discussed. Important visual system properties include a description of the eye's ability to resolve spatial and temporal patterns, and to perceive color distance and motion. The information presented is a background for the material in subsequent chapters. Key references have been provided to assist the reader who may wish to explore certain topics in greater depth.

The discussion of spatial and temporal modulation transfer functions (MTF) of the eye is relevant to information in chapters 3 and 4. Those not familiar with MTF of the eye should read this discussion.

2.1 Specification of the Physical Stimulus

This section consists of a brief presentation of the basic units of light measurement, including a discussion of the similarities and differences between the terms used by the physicist, and those used by the psychologist. Basically, an energy source (light) emits energy at a certain rate (radiant flux). The light falls on a surface. Some of the energy is reradiated by the surface (irradiance). When that energy is in the very narrow part of the electromagnetic spectrum called light the terms are photometric; e.g., luminous flux and luminance. Among many good sources for a more thorough and detailed treatment are Judd (1951), Riggs (1965a), Wyszecki and Stiles (1967), and Akin and Hood (1968).

2.1.1 Radiometric vs. Photometric Units

The energy that stimulates the eye and is capable of giving rise to a visual sensation is one small part of the electromagnetic spectrum. The visible spectrum extends from approximately 400 nm (nanometers, i.e., meters x 10^{-9}) to 750 nm. Perceived colors range from violet at the short end of this spectrum, through blue, green, yellow, and finally to red at the long end of the spectrum. There are several aspects, or dimensions, of this radiation which will be referred to from time to time throughout the book. These include specification of the total amount of energy per unit time (power) radiating from a point source, the power per unit solid angle, the power incident on a surface, and the power emanating from an

extended source. Two sets ' corresponding terms may be used to specify these quantities. Radiometric terms describe light in purely physical aspects, while photometric terms provide an indication of the effectiveness of the light as a stimulus for human vision. Historically, the two metrics were developed independently; today, because of the adoption of certain international standards, radiometric and photometric terms may be related mathematically to each other.

The basic difference between the metrics is that while a radiometric term is related to the total energy of the radiation without regard to its wavelength distribution, the corresponding photometric term essentially "corrects" for the capability of the human visual system to respond to radiation of different wavelengths. That is, energy at those wavelengths to which the visual system responds strongly is weighted heavily; energy at wavelengths that the eye cannot see is visually ignored. This distinction is stressed here because stimulus specification will usually be in photometric terms throughout the book; however, in certain instances a radiometric term must be used. Although only photometric terms are precisely correct for light energy as seen, the radiometric terms are not incorrect descriptors when discussing light. For instance, in specifying the stimulus to a certain (non-human) sensor, the radiometric term would be more appropriate.

Radiometric Units. To describe the total energy per unit of time emanating from a point source in all directions, the term radiant flux is employed. This term is therefore an expression of the power, P, radiating from the source, and is commonly measured in watts. The radiant intensity of this source is the amount of flux radiated per unit solid angle, or steradian, around a point source, and is $1/4\pi$ of the radiant flux from the source. To describe the radiation incident on a surface, the term irradiance is employed, which is expressed as watts per square meter of surface area. Irradiance is inversely proportional to the square of the distance from the source to the surface, and directly proportional to the cosine of the angle of incidence of the radiation to the surface, measured from a line perpendicular to the surface. Finally, when measuring the amount of energy emanating from an extended source rather than a point source, the appropriate term is radiance. Radiance is expressed as the radiant intensity per unit area of the source - specifically, as watts per steradian per square meter. It should be noted that the distance from the measuring instrument (or the human observer) is not important in calculating either radiance or its corresponding photometric term, luminance. While it is true that the amount of energy falling on the sensor from each theoretical point on the source decreases with the square of the distance from the sensor, it is also true that the density of these points (per unit solid angle subtended at the sensor) becomes theoretically greater, resulting in a constant radiance. This is strictly true, however, only in a vacuum, for the effect of the atmosphere is to decrease the radiance with increasing distance, a fact to be discussed in some detail in a subsequent chapter.

Photometric Units. The units used when describing light in photometric terms are analogous to those discussed above. The key to converting to photometric units lies in correcting for the spectral sensitivity of a "standard human" observer across the visible spectrum. Figure 2-1 shows the relative sensitivity of visibility; for precise conversion refer to a table of "luminosity coefficients" (e.g., Wyszecki and Stiles, 1967). The eye's sensitivity to a fairly bright light, expressed as a coefficient which ranges from 0 to 1.0, is greatest at 555 nm, and drops to practically zero above 720 nm or below 410 nm. Converting to photometric units is a matter of using these coefficients to obtain a weighted sum of energy (per unit time) across the spectrum. To convert from radiant flux to the corresponding photometric term, luminous flux, it has been established that at 555 nm, one watt of radiant flux corresponds to 685 lumens of luminous flux.

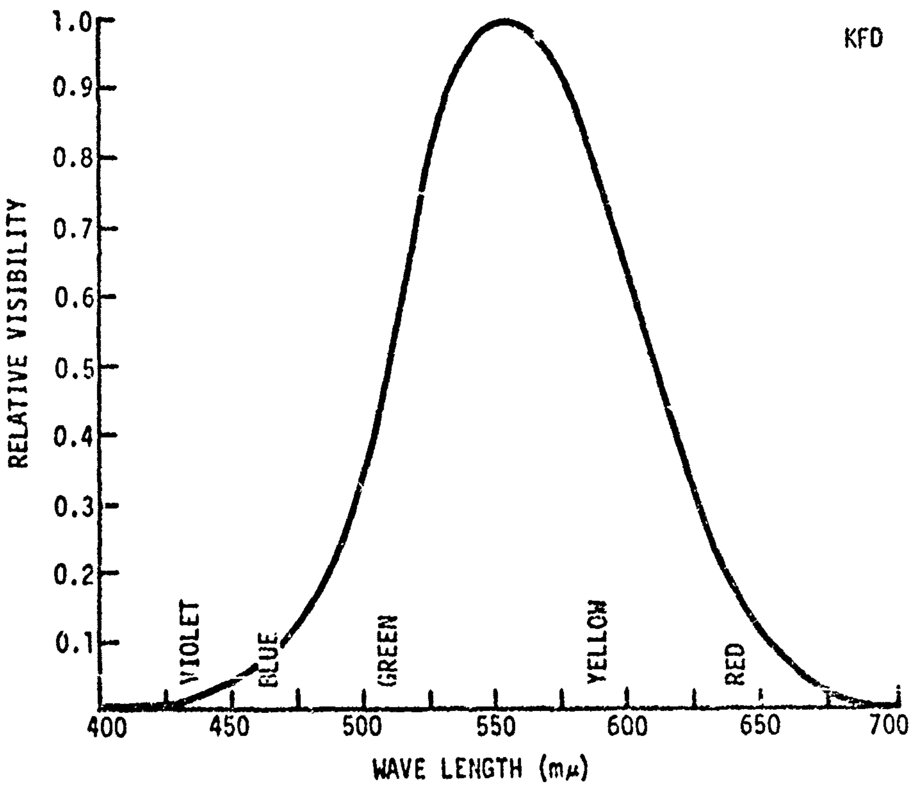

Figure 2-1. Visibility Curve for Human Eye

The luminosity coefficients employed will differ, depending on the brightness of the light. For fairly bright stimuli a function peaking at 555 nm is used (called the photopic luminosity function). For dim stimuli (approximately equivalent to the brightness of white paper at dusk, a different function is used (the scotopic luminosity function), which peaks at about 515 nm. The scotopic function reflects the fact that at low light levels the maximum sensitivity of the human visual system shifts in the direction of the lower wavelengths (see section 2.4.1).

The remaining photometric terms are equally similar to their radiometric counterparts. Luminous intensity is expressed in lumens/steradian, where 1 lumen/steradian = 1 candle. Illuminance is defined in terms of lumens/m^2, and luminance in terms of lumens/steradian/m^2, or candles/m^2. A great many different units have arisen over the years to express the above concepts, and conversion tables are readily available. One of the most frequently encountered units of illuminance is the foot-candle, and the millilambert is commonly employed to express luminance. Because measures of luminance will be most often encountered in this book, Table 2-I presents luminance values for some representative stimuli. Table 2-II summarizes the radiometric and photometric terms discussed in this section. Table 2-III is a series of conversion tables for photometric and radiometric units. Converting from radiometric to photometric units and back can be done only in the visible spectrum.

2.1.2 Description and Specification of Colors

Later chapters of this source book will discuss the role of colored stimuli (whether natural or artificially produced) in the acquisition of targets. Thus, readers unfamiliar with this topic should acquire a basic understanding of color nomenclature and of some human visual system properties relating to color perception. This section provides a discussion of the dimensions on which color varies, and presents a standard system of measurement and specification of colored stimuli.

Colored stimuli may be thought of as possessing three psychological dimensions: hue, saturation, and brightness. Hue is the attribute of color perception denoted by different color names, such as red, yellow, blue, green, etc. It is related to wavelength in that a light of one particular wavelength (monochromatic light) will vary in hue as its wavelength changes, a light at 700 nm being called red, a light at 500 nm being called green, and so on (assuming normal color vision). Different hues may be produced by different combinations of wavelengths as well, a fact to be discussed shortly. The attribute of saturation is sometimes referred to as the "purity" of a color, and may be thought of as its vividness or strength. One way to produce a desaturated color is by adding white light to a monochromatic stimulus. A completely desaturated color will appear as a shade of gray, the particular shade depending on the brightness of the stimulus. Brightness may be thought of as that attribute that changes as the physical intensity (e.g., luminance) of the stimulus increases or decreases.

TABLE 2-I

Luminance Values for Typical Visual Stimuli (Riggs, 1965a)

	Scale of luminance (millilamberts)
Sun's surface at noon	10^{10}
	10^{9} Damaging
	10^{8}
	10^{7}
	10^{6}
Tungsten filament	10^{5}
White paper in sunlight	10^{4} Photopic
	10^{3}
	10^{2}
Comfortable reading	10
	1 Mixed
	10^{-1}
White paper in moonlight	10^{-2}
	10^{-3}
White paper in starlight	10^{-4} Scotopic
	10^{-5}
Absolute threshold	10^{-6}

TABLE 2-II

Summary of Radiometric and Photometric Terms and Symbols (Riggs, 1965a)

Term	Symbol	Units
	Radiometry	
Radiant flux	P	watt = joule/second
Unit solid angle	ω	steradian = 1/4π sphere
Radiant intensity	J	watt/ω
Irradiance	H	watt/m^2
Radiance	N	watt/ω/m^2
	Photometry	
Luminous flux	F	lumen = watt/685 at λ = 555 nm
Luminous intensity (candlepower)	I	lumen/ω = candle
Illuminance	E	lumen/m^2 = lux = ~~meter-candle~~ = 0.0929 foot-candle
Luminance	L	lumen/ω/m^2 = candle/m^2 = 0.3142 millilambert = 0.2919 foot-lambert
Retinal illuminance	L.S	troland = luminance of 1 candle/m^2 viewed through a pupil of area S = 1 mm^2

TABLE 2-III

Conversion Factors

Here are a few tables of conversion factors. To convert any quantity listed in the left-most column to any quantity listed to the right, multiply by the factor shown.

Luminous Flux
(Intensity of a Source)

	Candle-power	Lumens	Watts	Ergs/second
Candlepower	1	4π	0.005882π (at 555mμ**)	5.882π × 10^{4} (at 555mμ**)
Lumens	1/4π	1	0.001471 (at 555mμ**)	1.471 × 10^{4} (at 555mμ**)
Watts	170/π (at 555mμ*)	680 (at 555mμ*)	1	10^{7}
Ergs/second	170/π × 10^{-7} (at 555mμ*)	680 × 10^{-7} (at 555mμ*)	10^{-7}	1

Illuminance
(Illumination incident upon a surface)

	Foot-candles	Meter-candles	Lumens/ft²	Lumens/meter²
Footcandles	1	10.764	1	10.764
Meter-candles	0.0929	1	0.0929	1
Lumens/ft²	1	10.764	1	10.764
Lumens/meter²	0.0929	1	0.0929	1

Luminance
(Surface brightness or reflected light)

	Candles/foot²	Candles/meter²	Footlamberts	Apostilbs***	Lamberts (Lumens/cm²)
Candles/foot²	1	10.764	π	10.764π	π/929
Candles/meter²	0.0929	1	0.0929π	π	π×10^{-4}
Footlamberts	1/π	10.764/π	1	10.764	10.764×10^{-4}
Apostilbs***	0.0929/π	1/π	0.0929	1	10^{-4}
Lamberts (Lumens/cm²)	929/π	10^{4}/π	929	10^{4}	1

Quantity of Energy Received By a Surface

	Meter-candle-Seconds	Footcandle-Seconds	Ergs/cm²	Watt-seconds/cm² or Joules/cm²
Meter-candle-Seconds	1	0.0929	1.471 (at 555mμ**)	1.471×10^{-7} (at 555mμ**)
Footcandle-Seconds	10.764	1	15.83 (at 555mμ**)	15.83×10^{-7} (at 555mμ**)
Ergs/cm²	0.680 (at 555mμ*)	0.0632 (at 555mμ*)	1	10^{-7}
Watt-seconds/cm² or Joules/cm²	6.80×10^{6} (at 555mμ*)	6.32×10^{5} (at 555mμ*)	10^{7}	1

Quantity of Energy Emitted by a Source

	Lumen-Seconds	Candle-power-Seconds	Watt-seconds or Joules	Ergs
Lumen Seconds	1	1/4π	0.001471 (at 555mμ**)	0.001471×10^{7} (at 555mμ**)
Candlepower-Seconds	4π	1	0.005882 (at 555mμ**)	0.005882×10^{7} (at 555mμ**)
Watt seconds or Joules	680 (at 555mμ*)	170/π (at 555mμ*)	1	10^{7}
Ergs	680×10^{-7} (at 555mμ*)	170×10^{-7} (at 555mμ*)	10^{-7}	1

*True only for monochromatic light at 555mμ. For other wavelengths in the visible region, multiply by the relative visibility factor for that wavelength.

**True only for monochromatic light at 555mμ. For other wavelengths in the visible region, divide by the visibility factor for that wavelength.

***Defined as 1 lumen per meter², occasionally incorrectly called meter-lambert.

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In real life monochromatic stimuli are rarely encountered. In most cases the colors we see are composed of mixtures of light at different wavelengths and intensities. Many different mixtures will produce identical sensations of color in the human observer. In other words, the human visual system, unlike the auditory system, is not capable of analyzing a stimulus that is made up of different spectral components. Instead, that stimulus is perceived in a unitary fashion. In a normal observer, a mixture of only three properly chosen wavelengths at the proper intensities is sufficient to match any color of the spectrum, as well as the non-spectral purples (which are additive combinations of red and blue). Thus colored television uses only three basic colors: red, green and blue. This statement should be qualified by stating that in certain cases it is not possible to match some highly saturated colors except by employing a "negative" amount of one of the three wavelengths. In practice this is achieved by placing that quantity on the other side of the "equation," namely, by adding that primary to the color being matched. This description of color mixtures pertains to the additive combination of lights, occurring for example, when different beams of monochromatic light are aimed at the same spot on a diffusing screen. The same rules of color mixture do not apply to the mixture of pigments, for in this case the process is one of subtraction. A pigment will reflect certain wavelengths and absorb the rest, so that two pigments mixed together will reflect only those wavelengths that are reflected in common.

Because of the fact that any perceived color can be described by specifying the quantities of only three primaries that are added together, a standardized system of color specification is possible. Such a system was developed when the Commission Internationale e l'Eclairage (CIE) (sometimes referred to as ICI) decided upon a set three primaries (since many sets are capable of producing all co ors) and derived the figures and tables necessary to specify colors in a standard way. The primaries actually chosen are mathematical abstractions, which are more saturated than physically realizable colors. They were selected because they have a number of convenient features, such as eliminating the necessity to deal with negative quantities. Figure 2-2 presents the "tristimulus values" for the three CIE primaries, $\bar{x}$, $\bar{y}$, and $\bar{z}$. These values represent the amounts of each primary needed to match light of any given wavelength λ. With these curves, or with the tables from which the curves were drawn (see example Wyszecki and Stiles, 1967), any colored stimulus may be described and plotted if its physical characteristics are known. To illustrate the procedure, one might first determine the energy of the stimulus at each wavelength across the spectrum (at for example, 10 nm intervals), then multiply the energy by the value of $\bar{x}$ at that wavelength, and sum across the spectrum. The quantity obtained in this fashion would be called X. The same procedure would then be followed to calculate Y and Z. The relative amounts, x, y, and z, of the three primaries may then be calculated by reference to the following equations: $x = X/X + Y + Z$; $y = Y/X + Y + Z$; $z = Z/X + Y + Z$. Since $x + y + z = 1$, the stimulus may now be plotted in two-dimensional space, on the CIE

chromaticity diagram in Figure 2-3. In this diagram which plots x versus y, the triangular-shaped figure represents all physically-realizeable colors. With the exception of the straight-line segment from 380 to 780 nm (which represents the locus of the non-spectral purples), any stimulus which plots on the boundary of this figure represents a color that cannot be distinguished from a monochromatic stimulus of the wavelength indicated. Colors in the interior of the figure are less saturated. The point labeled E represents a white light, defined as a mixture of equal amounts of the three primaries (it is located at the coordinates 0.33, 0.33).

The chromaticity diagram is useful in many ways, because it presents a geometrical way to visualize many facets of color mixture. For example, if colors representing any two points on the diagram are additively combined the mixture will be located somewhere on a straight line connecting the two points, the exact location depending on their relative intensities. The position of a stimulus on the diagram also permits it to be specified in terms of its "dominant wavelength" and its "excitation purity." The dominant wavelength is determined by drawing a straight line from E, through the coordinates of the stimulus, to the boundary of the diagram (spectrum locus). If, for example, the line intersects at 580 nm, the stimulus will appear to have a yellowish hue. The saturation of the stimulus, defined in terms of its excitation purity, is expressed as the percentage of its distance from E to the spectrum locus. With regard to brightness, a further useful feature of the CIE system is that it was constructed so that the value of Y is proportional to the luminance of the stimulus. Therefore, if two stimuli are being compared, by calculating Y for each stimulus it may be determined whether they match in luminance.

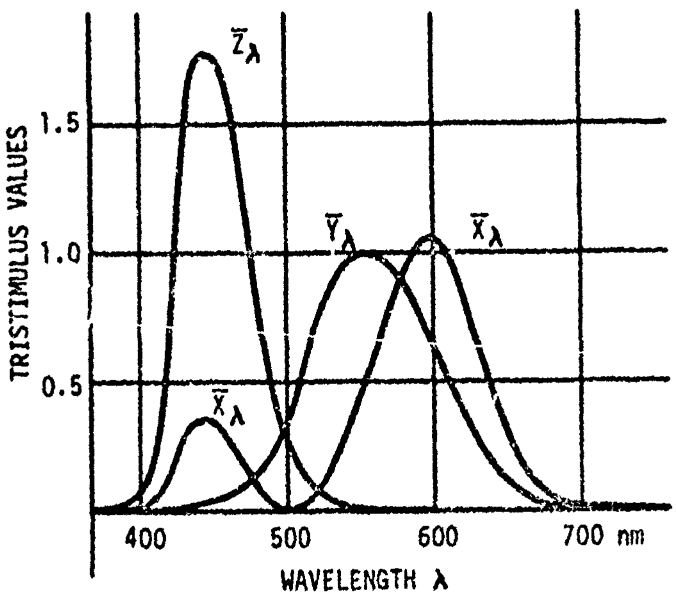
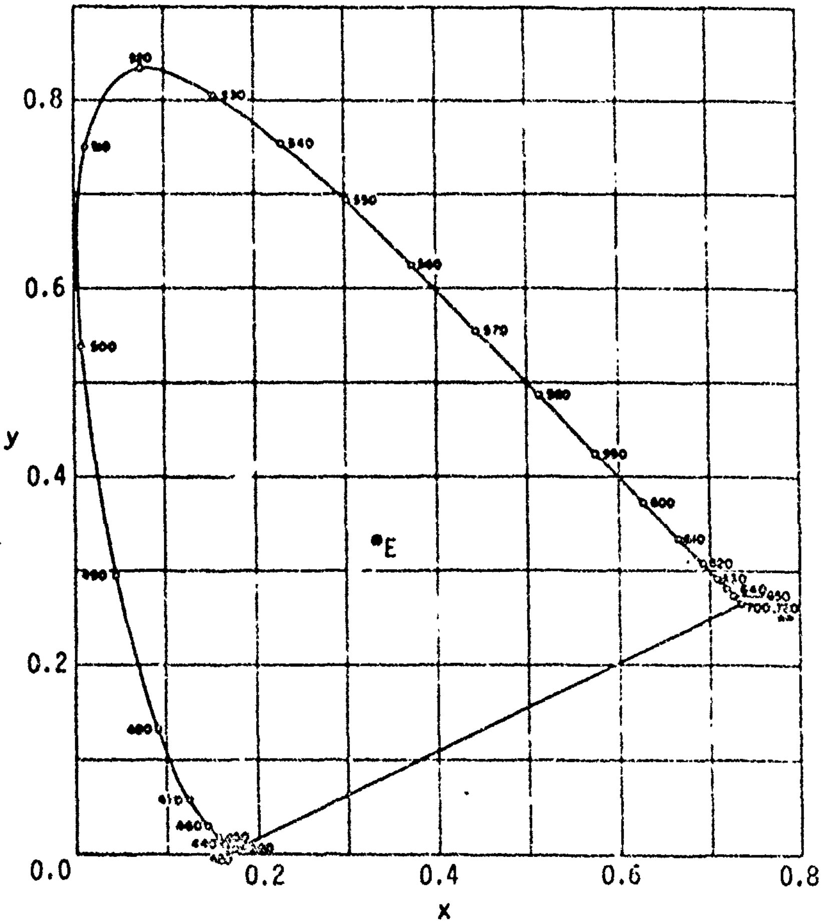


Figure 2-2. 1931 CIE Color-Matching Functions (from Wyszecki and Stiles, 1967)

Figure 2-3. 1931 CIE Chromaticity Diagram With Spectrum Locus, Purple Line, and the Chromaticity Point of the Equal-Energy Stimulus E. (From Wyszecki and Stiles, 1967)



2.2 Structure of the Eye

Figure 2-4 is a vertical cross-section of the human eye. For a more detailed treatment of the basic anatomy see, for example, Brown (1965b). The eye is approximately 25 mm in diameter, weighs about 7g, and includes a transparent bulge (the cornea) at the front surface which encompasses about one-sixth of the surface area. The major structures of interest in target acquisition include:

Retina. The retina is a membrane that lines the posterior portion of the eyeball. At this point light energy is changed into nerve impulses by receptors called rods and cones. The retina is a complex structure containing several layers of connecting nerve cells through which the light must pass before reaching the receptor cells. Because of this arrangement, the retina is said to be inverted or inside out. The distribution of the rods and cones is not uniform across the retina, as will be shown below.

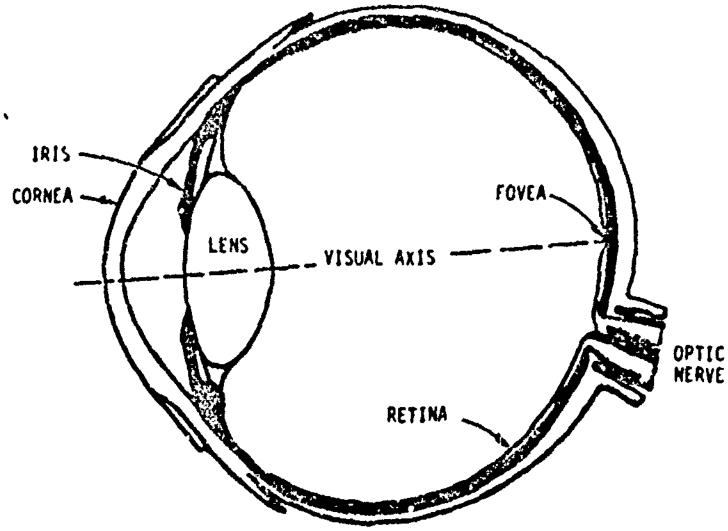


Figure 2-4. A Simplified Cross-Section of the Human Eye, Showing Principal Structures (from Cornsweet, 1970)

Optic Disc. Also known as the blind spot, the optic disc is the point at which the retinal nerve fibers unite into the optic nerve and leave the eye. There are no receptor cells located in the area; thus, no visual information is received here.

Fovea. This area is a small depression in the center of the retina and subtends an angle of 1.5°. It contains no rods but is densely packed with cones (approximately 147,000 per mm^2), with few nerve fibers intervening between the cones and the light source. The fovea thus provides a capability for perceiving fine detail.

Cones. The cones are receptor cells which provide both color and detail information. Functioning during relatively high illumination levels, cone vision is known as photopic or daylight vision. In the fovea, each cone connects via its own separate nerve pathway to the brain - one reason for the cone's ability to transmit detail information. Figure 2-5 illustrates the relative visual acuity as a function of distance from the fovea as well as the distribution of cones across the retina. Note the close correspondence between the acuity function and the cone distribution.

Rods. The rods are also retinal receptor cells. They are smaller than the cones. Rods are able to function during low levels of illumination when the cone system is inactive. Under low illumination the rods do not differentiate between colors, so that light is sensed, but not color. Rod vision is known as scotopic vision. Unlike the foveal cones, several rods share the same ganglion cell which leads to the optic nerve fiber. Rods are absent in the fovea, but increase in frequency up to approximately 20 degrees from the fovea (see Figure 2-5). As could be predicted from the distribution of rods, under scotopic viewing conditions maximum acuity is some distance away from the fovea.

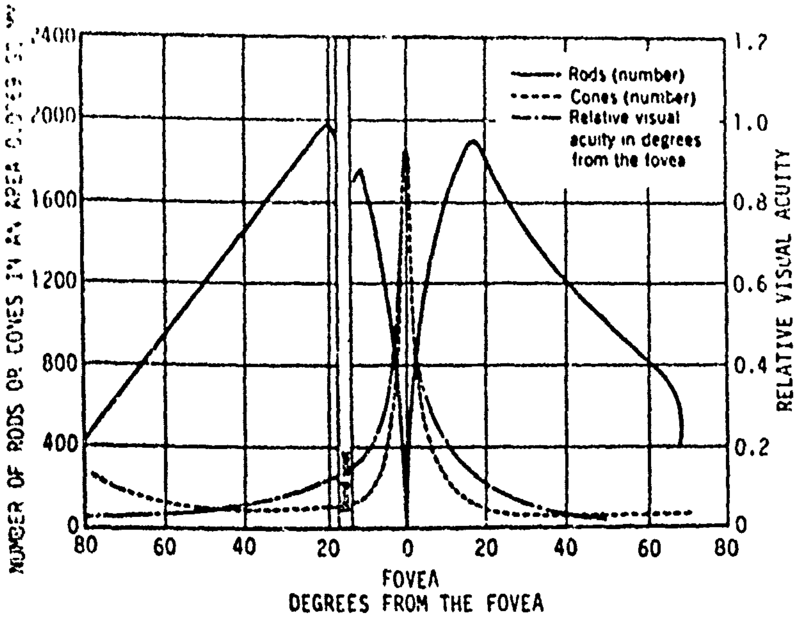


Figure 2-5. Distribution of Rods and Cones Along a Horizontal Meridian. Parallel Vertical Lines Represent the Blind Spot. Visual Acuity for a High Luminance as a Function of Retinal Location is Included for Comparison. (From Brown, 1965b. Data from Østerberg, 1935).

2.3 Spatial Variations

This section reviews basic data about the ability of the human visual system to respond to the spatial properties of stimuli, that is, to variations in brightness as a function of position. Information on the detection, recognition, or resolution of different kinds of targets is presented. How this ability is affected by stimulus factors, such as brightness, size, location, duration, motion, and shape is included. The subject of target-to-background contrast is given special consideration.

2.3.1 Static Visual Acuity

The traditional method of describing the ability of the human visual system to resolve small differences in spatial patterns has been via the concept of visual acuity. Acuity refers to the size of the detail that can just barely be resolved in some type of square wave pattern, i.e., a pattern characterized by abrupt transitions between light and dark areas. Thus, the quantity used to describe acuity is some measure of size. Generally, acuity is defined as the reciprocal of the threshold visual angle (in minutes of arc) of a critical detail of the target to be identified. Sometimes, particularly in clinical applications, acuity is expressed as a distance ratio; i.e., the distance at which a target is viewed, divided by the distance at which a critical detail of a target barely resolvable by a particular subject would subtend an angle of 1

minute of arc. An acuity score of 20/200 would therefore mean that at 20 feet the subject can barely resolve a target that has a critical detail of 1 minute when seen at 200 feet. It may be shown that this measure of acuity is equivalent to measuring it as the reciprocal of the threshold visual angle. In the above example, at 20 feet the visual angle of the critical detail would be 10 minutes; its reciprocal is thus 0.1, which equals 20/200.

The simplest method to calculate visual angle, which is accurate enough at the small angles encountered in measures of acuity, is (from Graham, 1951):

$$\beta = e/R \text{ (in radians), or } \beta = 57.3\ e/R \text{ (in degrees),}$$

where β = the visual angle, e is the critical dimension (height, length, etc.) of the target, and R is the distance to the target along the line of regard. These formulas overestimate β by 1 percent at a value of 10°, and by 3 percent at a value of 17°.

Although the description of acuity is fairly straightforward, there are a great many kinds of test objects that have been used to measure it. Riggs (1965b) has categorized these into four basic types of acuity tasks. These tasks will be summarized briefly below, in order to illustrate the kinds of acuity scores that may be expected in different situations.

Detection. In the case of visual detection, the observer is simply required to indicate whether or not a particular object is present in the field of view. This is the simplest of all acuity tasks, and may be further subdivided, depending upon the relationship between the target and the background. For a light target seen against a dark background, detection may more properly be termed a matter of absolute sensitivity, rather than acuity, since the visibility of such an object will depend on the amount of light reaching the retina, rather than the size of the object. Because of diffraction, below a critical size (about 10 seconds of arc) all targets will result in al :t the same retinal pattern, so that an acuity measure based on size is not possible. The most impressive acuity scores have been obtained with dark targets seen against a light background. It has been shown (cf. Geldard, 1953; Riggs, 1965b) that under optimal conditions a single dark line may be detected when its thickness is less than one second of arc.

Recognition. A recognition task demands that the observer identify the target or locate some critical detail. Two kinds of targets frequently employed in visual recognition tasks are the Snellen letters commonly found on optometrists' wall charts, and Landolt rings, which look like the letter C and may be rotated so that the critical gap appears in one of several locations. When measured with a recognition task, "normal" acuity is usually defined as a score of 1.0 (critical detail subtending one minute). Under optimal testing conditions, however (in

particular, high background luminance), acuity scores may be twice as high.

Resolution. In resolution tasks, repeatable (periodic) patterns are employed. The observer is required to indicate whether he discriminates among the elements of the pattern. Patterns typically employed are acuity gratings (alternating light and dark stripes), checkerboard patterns, and the like. Any single element in such patterns (such as a single line) would be clearly visible by itself, but in the presence of nearby contours the size of all elements must be increased manyfold in order for them to be distinguished from each other. In general, acuity scores measured with resolution targets are similar to those obtained for recognition stimuli. Thus, for example, in the case of a grating with light and dark stripes of equal width, the minimum stripe width necessary for resolution is approximately 1 minute of arc.

Localization. The fourth type of acuity task depends on the ability of the observer to discriminate displacements of one part of the stimulus in relation to another part. The most common example of the localization task is the measurement of vernier acuity, which represents the ability to determine whether the lower segment of a vertical line is displaced laterally from the upper segment. Vernier acuity scores are typically quite high. It is possible to detect displacements on the order of a few seconds of arc, nearly as small as the detection thresholds discussed previously.

Several stimulus factors are important in influencing the resolving power of the visual system. Thus, it is not possible to specify visual acuity without specifying the conditions under which it is measured. Some of the more important variables on which acuity scores are dependent will be discussed in the following paragraphs. This discussion will be restricted to those parameters likely to be relevant to target acquisition problems. For a treatment of other parameters of theoretical importance, see, for example, Riggs (1971).

Acuity scores are strongly dependent upon brightness, or intensity, factors. If the brightness levels of the object being viewed and the background against which it is viewed are too low to stimulate the cone receptors of the retina (i.e., below the photopic visibility threshold), acuity will be very poor. As shown in Figure 2-5, acuity is relatively poor in those regions of the retina where rods are located. Even at higher intensity levels, when the cones are functioning, acuity is still related to intensity over a wide range of intensities. The most thorough investigation of this phenomenon has been conducted with recognition tasks; some representative data are presented in Figure 2-6. In this figure it may be seen that acuity is poor in the scotopic (rod) range, but rises rapidly over a large part of the photopic (cone) range. Curves of essentially the same form have been obtained with a variety of recognition test objects, and with resolution tasks as well. When test objects are brighter than the background, however, acuity is maximum at moderate intensity levels, and drops sharply at high intensities (Bartley, 1951).

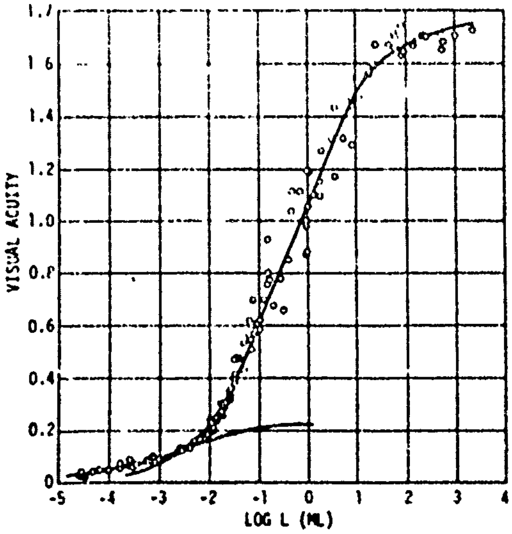


Figure 2-6. Visual Acuity as a Function of Luminance, in a Recognition Task. Separate Curves are Fitted to the Rod (Low Luminance) and Cone (High Luminance) Portions of the Data. (From Hecht, 1934, and Riggs, 1965b).

Another parameter of great importance for the determination of visual acuity is the brightness contrast between target and background. In the case of recognition and resolution tasks, as well as for detection, it has been found that acuity increases with an increase in contrast. Since it has special practical interest for the target acquisition process the topic of contrast will be discussed later in this chapter.

The level of brightness to which the eye is adapted prior to being tested has an effect upon the acuity level attained. In general, acuity increases as the luminance of the test field increases, up to the level at which the eye has been previously adapted; acuity then decreases at test luminances higher than the adapting luminance (Craik, 1939). In practical terms, this indicates that, when possible, the observer should adapt to the ambient luminance level prior to attempting any fine discriminations.

Studies concerning the effects of different kinds of illumination on acuity have shown that acuity scores are affected by the wavelength distribution of the light employed. Monochromatic light from the middle of the visual spectrum has been found superior to white light (Riggs, 1965b), while it is known that light from either spectral extreme (blue in particular) results in relatively poor acuity scores.

Finally, the location of the target within the field of view has a large effect on the size of an object that is barely detectable. As was mentioned previously, images falling in the peripheral areas of the retina are much more difficult to perceive, except under very low illumination. Figure 2-7 presents some representative data, showing the extent to which an object seen in daylight must be enlarged in order for it to be detected as its distance from the visual fixation point increases both laterally and vertically.

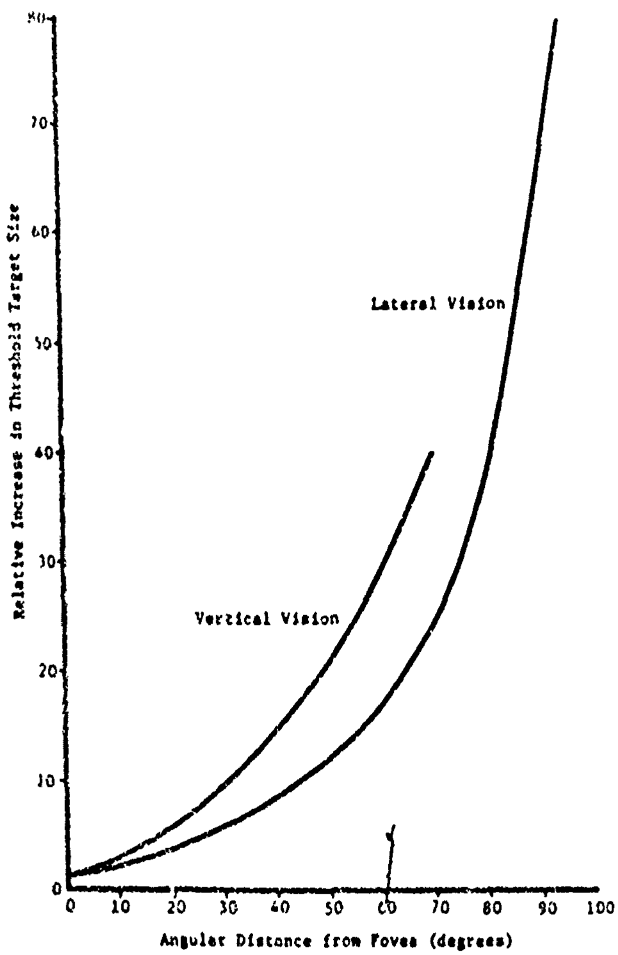


Figure 2-7. Variation in Threshold Visual Acuity as a Function of Angular Distance from the Fovea. (From Dugas, 1962).

2.3.2 Dynamic Visual Acuity

Dynamic visual acuity refers to the ability of an observer to detect, recognize, or resolve a target when either the observer, the target, or both are moving. Miller and Ludvigh pioneered the study of dynamic visual acuity in the 1950's. To illustrate angular velocity in familiar terms, Ludvigh and Miller (1954) used the following examples:

> "...an automobile traveling 30 miles per hour, and passing perpendicularly to the line of view at a distance of 30 feet provides an angular velocity of about 85°/second and a fairly fast pitched ball delivered to the catcher and viewed from the first base provides an angular velocity of approximately 100°/second."

The Miller and Ludvigh findings were later investigated and generally supported by Burg and Hulbert (1961) as follows: (1) Miller and Ludvigh

found little correlation between static and dynamic acuity. Burg and Hulbert found low but significant correlations, which they felt were due to the high degree of similarity between the static and dynamic targets as well as to their more heterogeneous subject population. (2) Acuity for a moving target deteriorates markedly and progressively as the angular velocity of the target increases. (3) Dynamic visual acuity performance can be improved both through practice and through increased illumination.

Miller and Ludvigh (1953) also found superior dynamic acuity scores to result from relative motion in the vertical plane, in comparison with relative motion in the horizontal plane. Their results indicated thresholds to be approximately 0.5 to 1.0 minute of arc lower in the vertical plane.

Snyder and Greening (1965) reviewed the studies by Miller and Ludvigh and Burg and Hulbert and noted that in all their experimental conditions the distance between observer and target remained constant. Although the direction of motion was varied in either a vertical, horizontal or circular plane about the observer's head, stimulus motion toward or away from the observer was not studied. Snyder and Greening (1965) included a component of motion toward the observer which they felt was meaningful since in most practical situations the target does not remain equidistant from the observer.

Miller and Ludvigh described the function relating dynamic visual acuity to angular velocity by a curve of the form $Y = a + b X^3$, where Y is the visual acuity in minutes of arc, X is the angular velocity in degrees per second, a is the intercept constant (representing zero angular velocity -- i.e., static acuity), and b is a curve fitting component which varies according to the illumination, direction of motion, and other conditions. Snyder and Greening used a formula of the same general form as the Miller and Ludvigh formula.

Figure 2-8 presents both an average that was determined empirically for the Miller and Ludvigh subjects (adapted by Dugas, 1962) and the Snyder and Greening results, replotted and extended. The Miller and Ludvigh curve is represented by the equation $Y = 3 + 2.9X10^{-6}X^3$ and the Snyder and Greening curve is represented by $Y = 1 + 0.37 X^{2.34}$. Snyder and Greening pointed out that their lower static threshold was probably due to conditions in their study such as high contrast, high resolution and low glare targets. Note that since the functions in Figure 2-8 are positively accelerated curves rather than straight line functions, this figure provides an example of the non-linear behavior of the human visual system.

Dugas (1962) pointed out that under actual flight conditions vibration effects, atmospheric attenuation, low contrast targets and viewing window distortions would reduce dynamic visual performance. She cited airborne tests (e.g., Goodson and Miller, 1959) that have indicated operational thresholds to be as much as 30 percent greater than the ideal laboratory conditions.

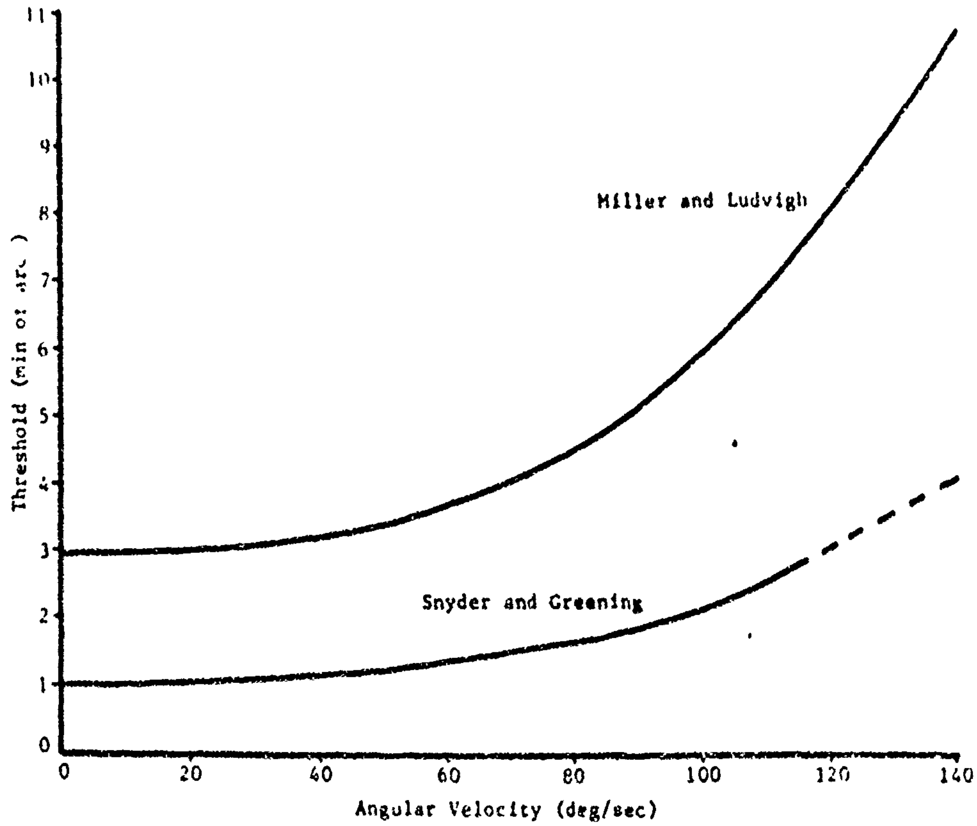


Figure 2-8. Dynamic Acuity as a Function of Angular Velocity. Upper Curve from Dugas (1962); Lower Curve from Snyder and Greening (1965). Dashed Portion is an Extrapolation.

2.3.3 Form Perception

Form perception, the ability to distinguish objects on the basis of shape, depends not only on visual acuity but also on the observer's previous experience. The way in which we perceive forms has been investigated for years by psychologists. Unfortunately, the literature on form perception consists primarily of basic laboratory experiments and contradictory theories. Wulfeck (1958) pointed out that although there is a need for a clear definition of the characteristics of shapes that make them easy to distinguish, there has been only limited success in analyzing this type of discrimination.

Basic to the discussion of form perception is the psychological concept of figure and ground (analogous to target and background). Rubin (1915, 1921) cited by Hochberg (1971) classified some of the striking differences between figure and ground as follows:

1. The figure has shape, while the ground is relatively shapeless.

2. The ground seems to extend behind the figure's edge.

3. Thus, the figure has some of the character of a thing, whereas the ground appears like unformed material.

4. The figure usually tends to appear in front, the ground behind.

5. The figure is more impressive, more apt to suggest meaning, and better remembered.

In the case of target acquisition, form perception is inherently necessary, but little has been written on the application of this type of perception to military settings. Shape discrimination becomes more difficult under conditions of reduced visibility, where the outline of the shape is obscured, such as by fog, haze, dust, or turbulent atmospheric conditions or by detection at long distances, at night, or during low altitude high speed reconnaissance.

Zusne (1970) listed several classifications of form perception tasks in military and industrial settings (see Table 2-IV). The tasks were based on the discrimination of a figure on a noisy ground, with the noise varying in amount and degree of organization. Visual noise is defined here as unwanted stimuli in the scene which may interfere with the acquisition of the target.

TABLE 2-IV

Effects of Type and Degree of Noise on Figure/Ground Relationships in Military Applications

NOISE TYPE	EXAMPLE	RESULT
Noiseless	Instruments, scales	Figure stands out from ground.
Organized Noise	Aircraft painted with contour camouflage patterns	Ground and figure appear as one, contours blended.
Random Noise	Jeep viewed in rocky terrain	Figure obscured by noise in ground (depending on degree of noise), yet they are separable.

2.3.4 Brightness, the Effects of Contrast

In many target acquisition situations we can consider acuity (especially detection acuity) as a form of brightness discrimination. In other words, we consider the resolving power of the human visual system in terms of the amount of illumination or contrast necessary to

cause an object to become visible. In this context the dependent variable of interest is the amount of contrast at which an object is just barely visible, according to some criterion, such as detectable on 50 percent of the trials. A considerable amount of work has been done on determining contrast thresholds and a summary of this data is necessary to understand the target acquisition process. The following presents information which is important in understanding the interrelationships between the several variables of importance. The data are important; they can be considered to represent a "best case" target acquisition situation, from which real-world capabilities can be scaled downward.

Contrast has many different definitions. The definition to be used here is that used by Blackwell (1946), in which

$$C = \frac{B_t - B_b}{B_b}$$

where C is contrast, B_t refers to the brightness (or luminance) of the target, and B_b is the brightness of the background against which it is viewed. (In subsequent chapters, if not otherwise specified, Blackwell's definition of contrast is used.) With this formula contrast values may be either positive or negative; in the case where the target is brighter than the surround, C ranges from 0 to ∞, while for a target dimmer than the background, C ranges from 0 to -1. Frequently no distinction is made between targets brighter than the background (sometimes called positive stimuli) and targets darker than the background (negative stimuli), since little difference has been found between them in terms of the detection thresholds obtained. An exception to this statement occurs with large stimuli and low background luminances, for which Blackwell (1946) has found 20 percent lower thresholds for negative stimuli.

By far, the most comprehensive studies of contrast thresholds are those performed by Blackwell and his colleagues initially during World War II at the Tiffany Foundation. The typical procedure involved the direct binocular viewing of an observation screen of uniform brightness, on which a circular target (darker or lighter) would be superimposed. The subject was required to indicate whether or not he detected the presence of the stimulus. Contrast threshold was defined as the contrast resulting in a 50 percent detection probability.

Blackwell and Taylor (1969) have compiled and integrated information from many separate experiments. Their survey involves over one million separate observations. Figures 2-9 through 2-14 present some of the data most applicable to the subject content of this book. Figures 2-9 and 2-10 summarize contrast threshold data on targets appearing in the most favorable location (as specified by the subjects), and with unlimited viewing time (actually, between 10 and 30 seconds, as further increases in viewing time did not increase detection probability). The two figures represent

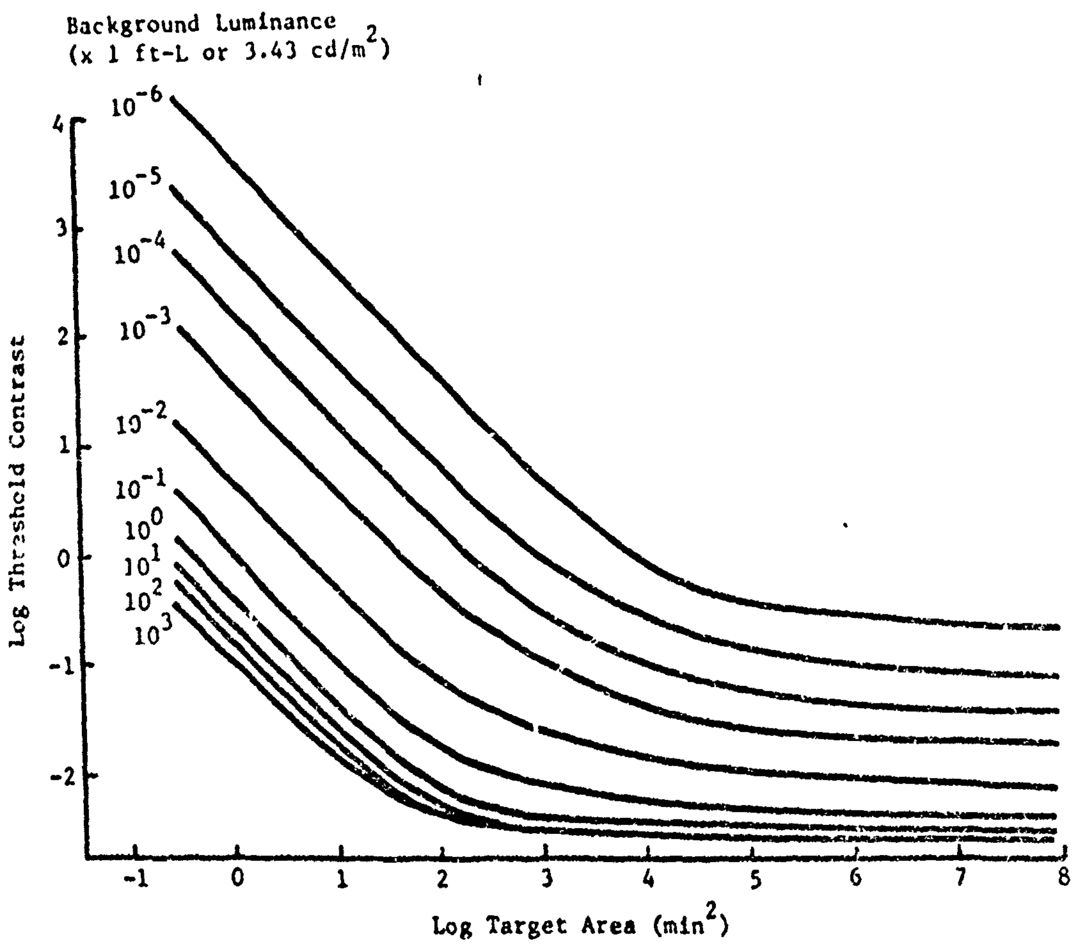


Figure 2-9. Consolidated Data for Unlimited Time of Observation, with Target in the Most Favorable Possible Location. (From Blackwell and Taylor, 1969).

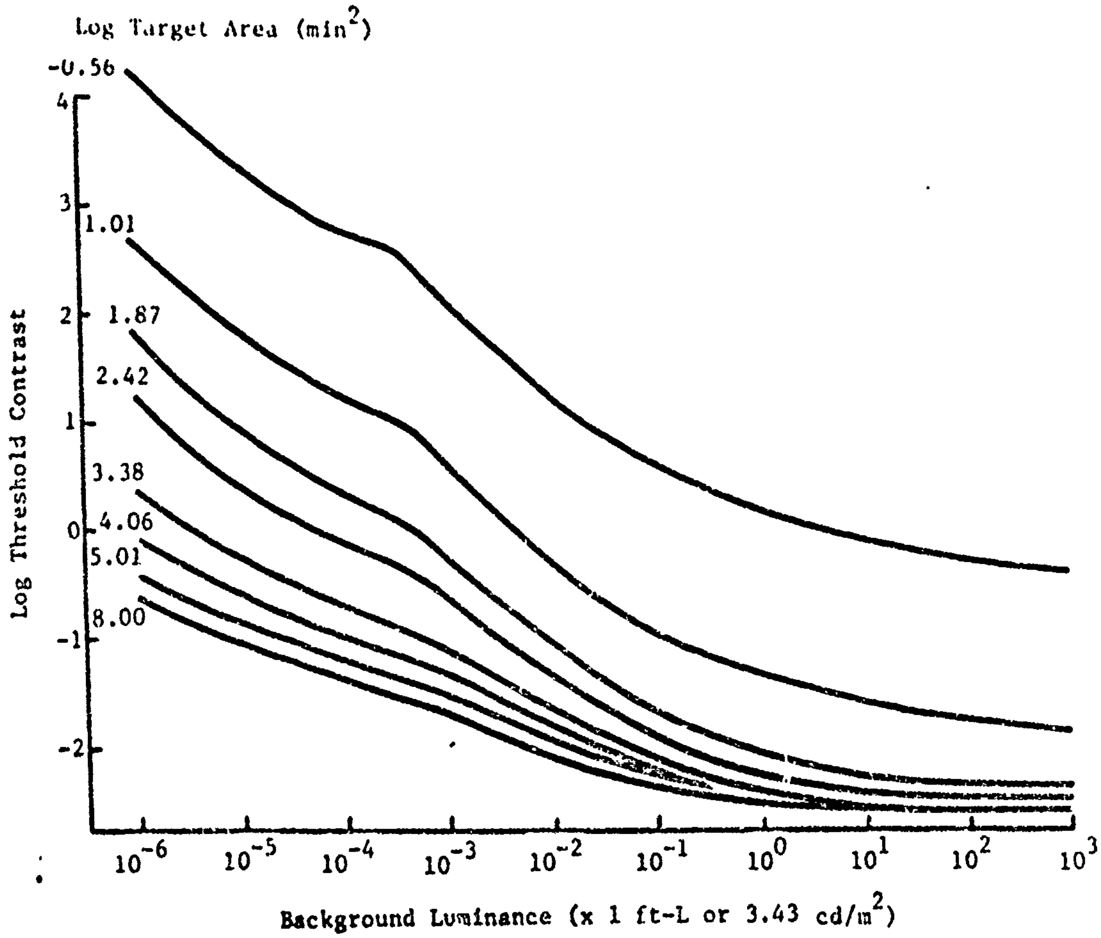


Figure 2-10. Consolidated Data for Unlimited Time of Observation, with the Target in the Most Favorable Possible Location. (From Blackwell and Taylor, 1969).

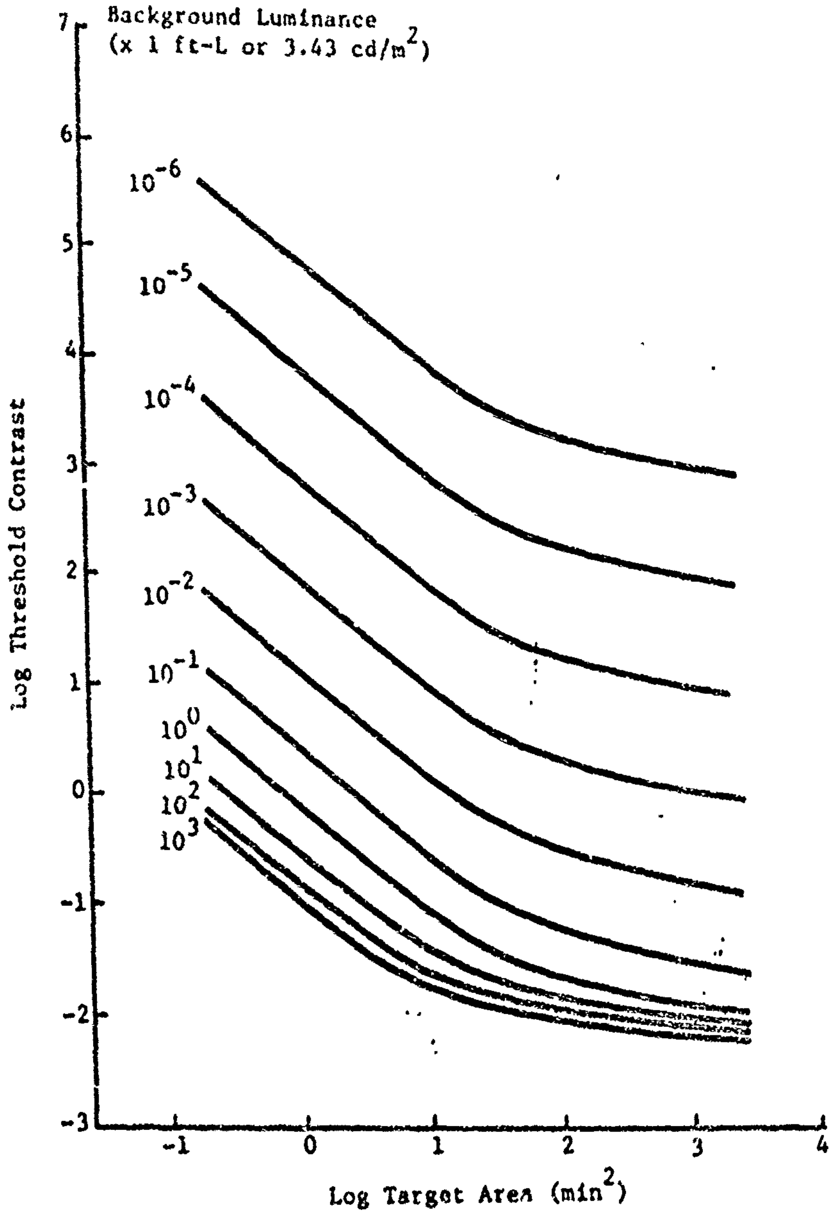


Figure 2-11. Consolidated Data for 1 Second Exposure with the Target Directly on the Visual Axis. (From Blackwell and Taylor, 1969).

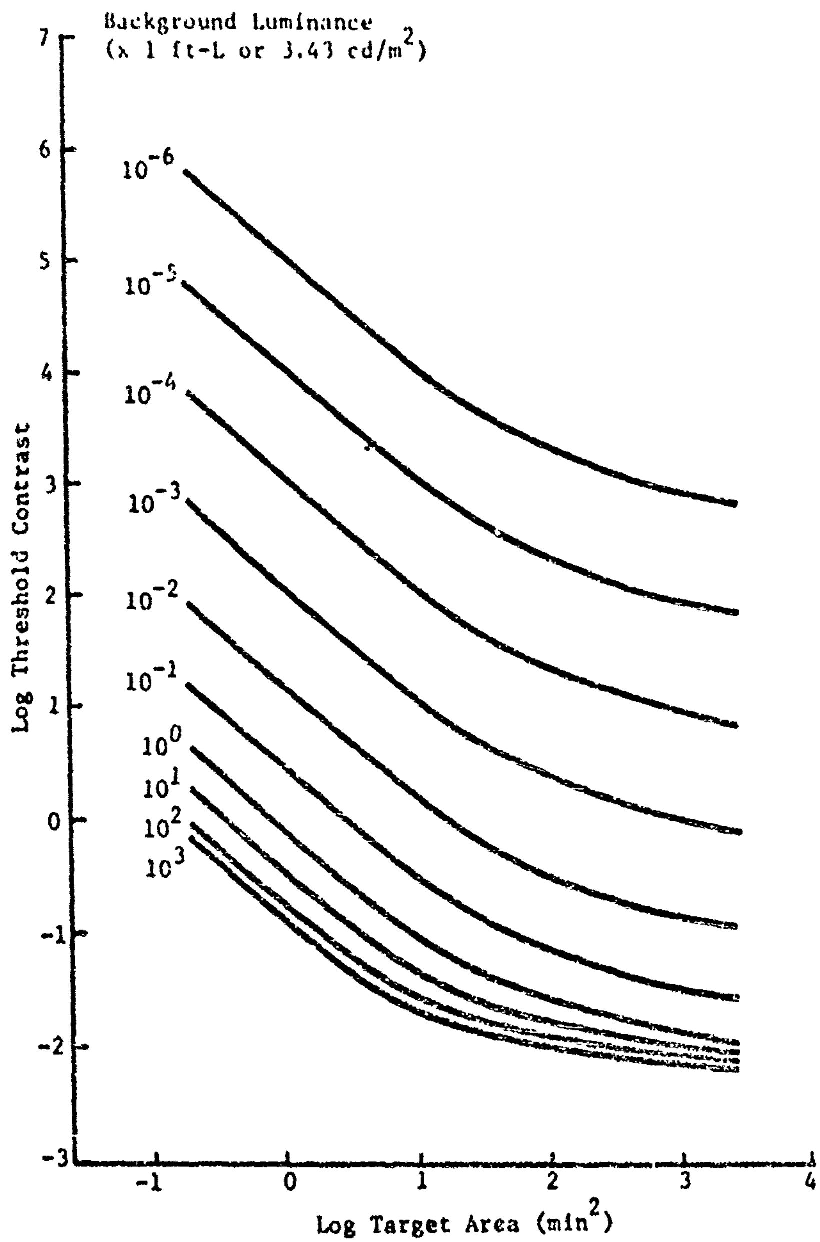


Figure 2-12. Consolidated Data for 0.33 Second Exposure with the Target Directly on the Visual Axis. (From Blackwell and Taylor, 1969).

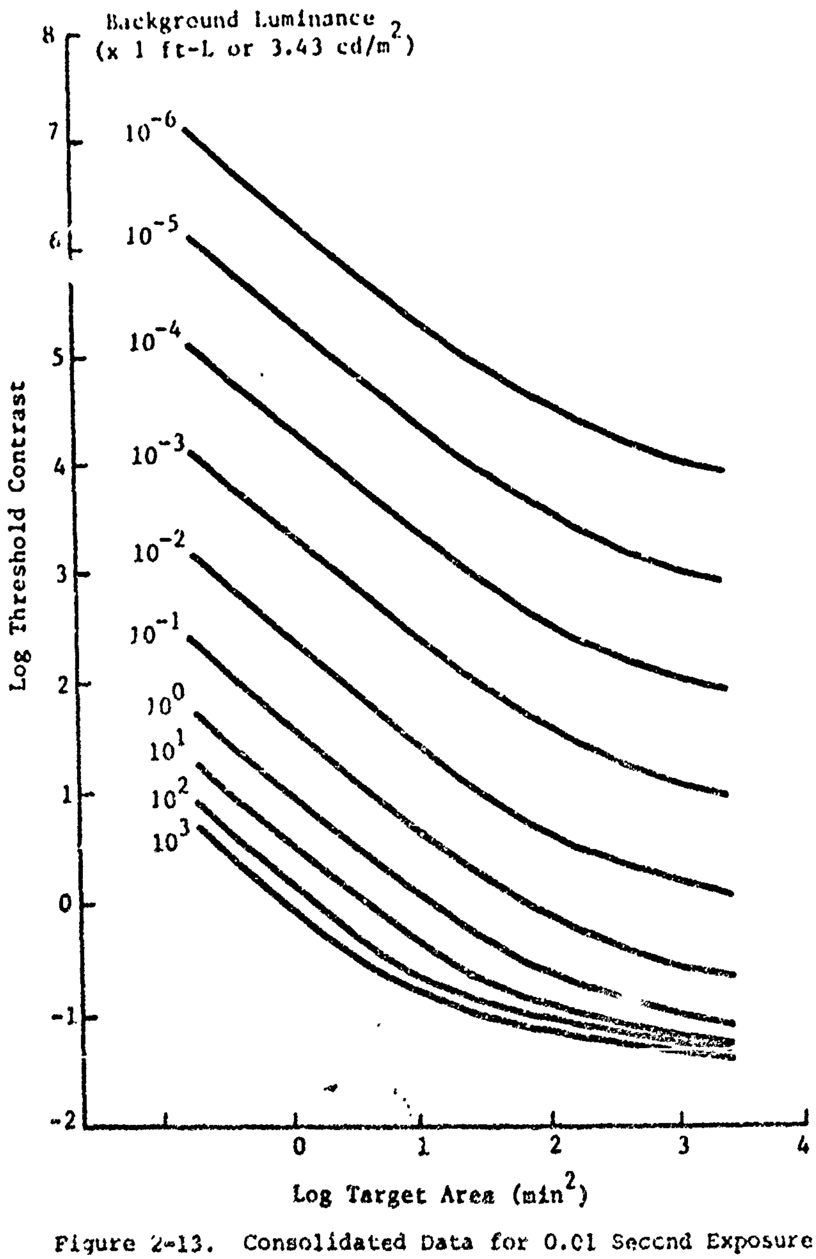


Figure 2-13. Consolidated Data for 0.01 Second Exposure with the Target Directly on the Visual Axis. (From Blackwell and Taylor, 1969).

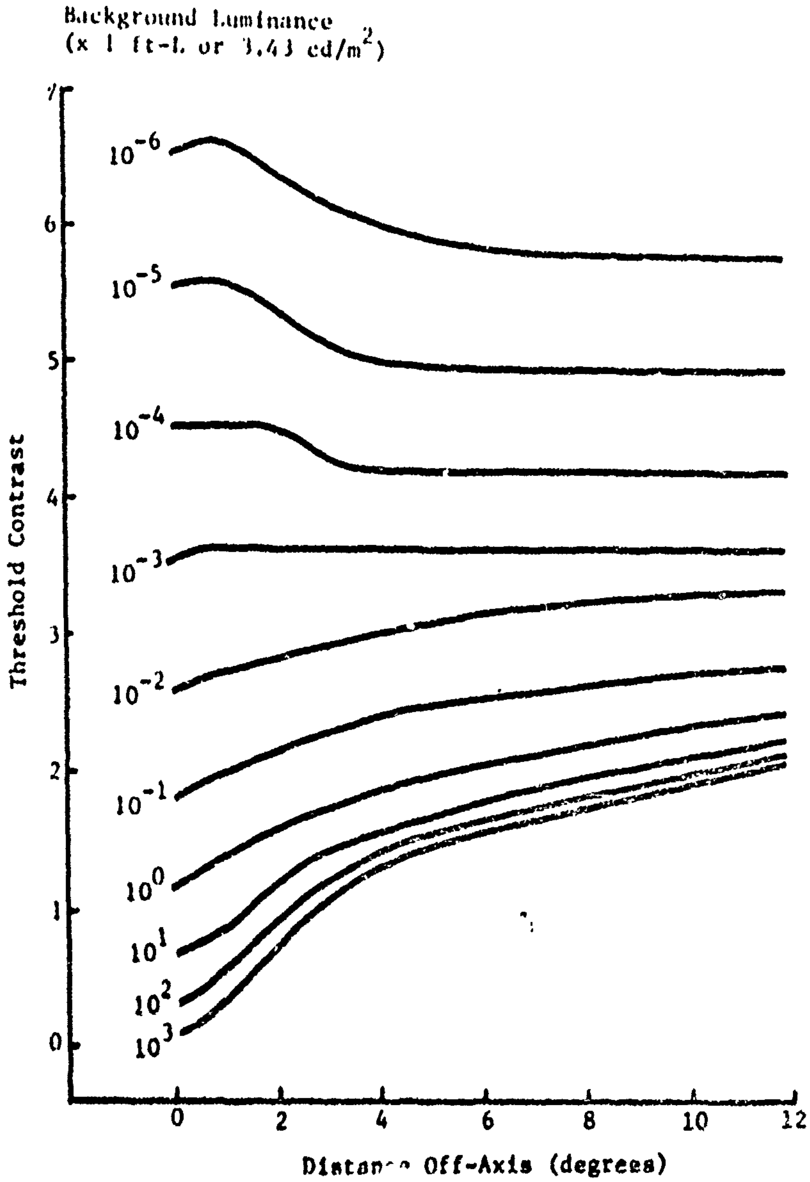


Figure 2-14. Visual Detection as a Function of Background Luminance and Off-Axis Location. Log Target Area (min^2) was -.11 (Target Diameter = 1 Minute). Exposure Duration was 0.01 Second. Location of Target Varied in Azimuth for Each Off-Axis Distance Studied. (From Blackwell and Taylor, 1969).

the same data, plotted in different ways. These figures illustrate the importance of two prime determinants of detection: background luminance and target size. It may be seen that as background luminance increases over a range of nine log units, detectability as measured by threshold contrast improves by a factor of from two to over four log units. As target size increases, detectability increases, up to a point; beyond a size of about 2° (log target area of approximately 4.0), the effect is negligible, except at low background luminances. The discontinuities in some of the curves of Figure 2-10 are due to a shift in the preferred target location. At higher background luminances, on-axis (foveal) locations were preferred, while off-axis locations were favored at low luminances.

Figures 2-11 through 2-13 present a family of curves in which the target was always presented where the subject was fixating (on-axis location). The three figures represent different durations of stimulus presentation, from 1 second to 0.01 second. The maximum target size employed in these studies was a disc with a diameter of 1°, in order to ensure that all targets fell within the foveal area. These figures are straightforward and demonstrate that for a given target size and background luminance, the contrast must be increased in order for a target to be seen at progressively shorter durations.

Finally, Figure 2-14 presents data showing the extent to which detection performance changes as the target is presented farther and farther off the visual axis. The data presented are for one target size (1 minute disc diameter), and one observation time (0.01 second). It may be seen that this function is strongly related to the level of background luminance, with foveal presentation resulting in best detection at high luminances, and poor detection at low luminances. This phenomenon is well known and of considerable practical importance in target acquisition. It means that individuals performing detection tasks at night (e.g., observers, night sentries) must learn not to look directly at very dim objects, but rather look slightly to one side. As Blackwell and Taylor point out, off-axis data are still relatively incomplete, and further research is progressing along these lines.

The above figures have presented some of the information needed to describe the general detection characteristics of the human visual system. It should, however, be noted that these data by themselves may have little practical utility as hard and fast guides to expected performance in actual operational situations. In the laboratory environment the subject is aware that a target is about to be presented (and in many cases he knows where it will appear); the target is regular in shape; it is seen against a uniform background; forced choice is used and many of the environmental conditions are unrealistic from an operational standpoint, such as the lack of noise, motion, vibration, distraction, and stress. The philosophy supporting the laboratory approach has been that by collecting a great deal of data under very carefully controlled conditions, a useful reference base may be established, to which various correction factors may be applied to predict detectability under different conditions

of interest. For example, in discussing some studies investigating target detection with non-uniform backgrounds, Blackwell and Taylor (1969) suggest that "...the most important consideration is the luminance contrast existing between the target edge and its immediate background. Data obtained with backgrounds of uniform luminance represent this case well. It is almost certain that background luminance non-uniformity will affect target detectability to an appreciable extent under some conditions, but again it appears likely that the effect can be taken into account as a correction factor applied to the data obtained with uniform backgrounds." One attempt to apply correction factors to laboratory data is that of Davies (1965), who discusses the similarities and differences among a number of laboratory detection experiments, in terms of the experimental procedures employed, and compares laboratory data with data obtained from some actual flight experiments. His paper is a good source of information on which data to employ, and which conversion factor to apply, depending upon the type of situation for which one wishes to predict thresholds. As a general guide, Davies recommends the addition of 0.75 log units to the contrast threshold curves for the 0.33 second foveal viewing situation.

There are many studies that have tried to bridge the gap between well controlled laboratory and the highly complex real world situation. Many of these studies will be noted throughout this book. But there is no question that there are still a great many gaps in our understanding of the stimulus factors influencing detection. What seems to be needed is an analytic approach by which a target and its environment can be characterized, and which will permit the prediction of the response of the visual system to a wide variety of intensity distributions. One such approach will be discussed in the last sections of this chapter which provide an introduction to the application of Fourier analysis techniques to human vision. It is hoped that this approach will prove to be the unifying concept for much of the material in this book.

2.4 Temporal Variation

This section will present basic information pertinent to an understanding of some of the temporal properties of the human visual system. Thus, it is analogous to the previous section, which dealt with visual response to spatial variations. Further information concerning the sensitivity of the visual system will be presented, followed by a discussion of dark and light adaptation, glare, flashblindness, and the perception of flicker.

2.4.1 Sensitivity of the Visual System

As discussed earlier, there are two types of light-sensitive receptor cells located in the fovea: the cones which function during relatively high illumination levels (photopic vision), and the rods which function during low levels of illumination (scotopic vision). Upon entering a

dark room from broad daylight there is not an immediate switch from cone to rod vision and it is difficult to see much of anything for a few minutes. Visibility gradually increases, until the surroundings are more readily perceived; the visual system has thus become adapted to the new level of illumination. Conversely, if the individual leaves a dark room for broad daylight, vision may again be impaired until the system is light adapted. The entire range of luminance to which the visual system is capable of responding is on the order of eight log units or a ratio of 100,000,000:1. When luminance gradually decreases from afternoon through twilight to night time levels, the transition from cone to rod vision is comparably gradual, the transition zone being known as mesopic vision.

The eye is not equally sensitive to radiant energy from all parts of the visual spectrum, nor are the cones and rods maximally sensitive to energy at the same wavelengths. The relationship between rod and cone vision has been studied by many investigators and typically quantified in the form of photopic and scotopic relative luminosity curves. Figure 2-15 presents the relative amounts of radiant flux required for both cone and rod thresholds for wavelengths between 400 and 700 nm. The scotopic curve is based on subjects' responses to discrete wavelengths along the spectrum while the eyes are dark adapted. The photopic curve in Figure 2-15 was determined when the stimulus intensity was well above cone threshold. Thus, the scotopic curve represents rod sensitivity to the spectrum while the photopic curve represents sensitivity.

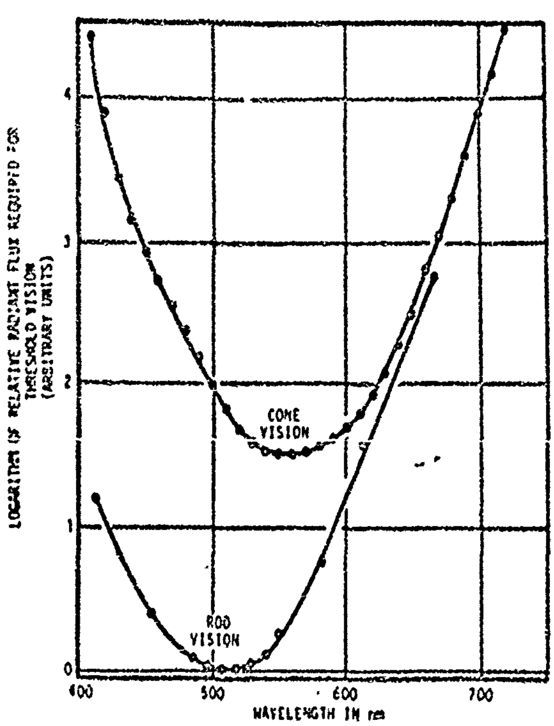


Figure 2-15. Relative Radiant Flux Required to Stimulate the Cones and Rods Along Different Wavelengths (From Chapanis 1949).

When examining Figure 2-15, it is obvious that not only are the rods sensitive to lower levels of illumination than the cones, but the rods are most sensitive to energy around 510 nm (green region), while the cones are most sensitive to 555 nm (yellow-green region). This shift in maximum sensitivity, called the Purkinje shift, can be perceived in twilight. The result of the Purkinje shift is that under scotopic visual situations, green, blue-green, and blue objects appear relatively brighter than they do under photopic levels of illumination. Therefore, although various colored lights, for example, may appear equally bright at night from a particular distance, the blue, blue-green, and green lights will be visible for much greater distances than other colors.

The vertical distance between the rod thresholds and cone thresholds in Figure 2-15 is called the photochromatic interval. It represents intensities that are above rod threshold so that light is perceived, but below cone threshold, so that the light is colorless. The photochromatic interval represents the logarithm of the ratio of cone threshold to rod threshold for each wavelength. Thus, the interval represents the factor by which the radiance must be multiplied to pass from colorless vision to color vision (Graham 1965b).

There are stimulus variables other than wavelength that affect threshold measurements for the rods and cones. These variables include the position of the light on the retina, the size of the retinal area which is stimulated, and the duration of the test stimulus.

Position on the Retina. In order to measure cone threshold, the stimulus light is directed on the fovea, where rods are completely absent. Rod thresholds should be measured where the rods are packed most densely, an area 20 degrees outward from the fovea. Hecht et al. (Cornsweet, 1970) presented their subjects with dim point sources of light to fixate upon, while the test stimulus was flashed 20 degrees from the fixation point, in order to stimulate the rods.

Size of the Area Stimulated. As mentioned previously in this chapter, many rods connect into one nerve fiber. In the area where the rods are most dense, the rod-to-nerve cell ratio is about 300:1. Hecht et al. (Cornsweet, 1970) determined that as long as the test light diameter is less than about 10 minutes of arc the total light energy necessary for a sensation is independent of the diameter of the stimulus. This phenomenon is called spatial summation. As the stimulus diameter increases above 10 minutes, the threshold energy will also increase.

Duration of Test Stimulus. As long as the test stimulus is presented for no longer than about 0.1 second, its actual duration has no effect on threshold, provided the total amount of energy in the flash remains constant. When the duration exceeds 0.1 second, progressively larger total amounts of light energy will be required for the stimulus to be perceived. This process, temporal summation, which is analogous to spatial summation, will be discussed later in this chapter.

2.4.2 Dark Adaptation

Although vision is most acute in daylight, there are times, such as flying at night, when the eye must function during scotopic levels of illumination. In order for the eye to function at its maximum potential, it must be adapted to the dark. There are two steps in dark adaptation: initially there is a rapid decrease in threshold, leveling off after about 10 minutes, followed by a more gradual decrease in threshold which continues for about 30 minutes. Dark adaptation occurs separately for each eye and is virtually complete after 40 minutes.

The initial rapid phase is due to the cones adapting to the decreased illumination, while the secondary phase represents the adaptation of the rods, which have an extensive range of adjustment compared to the cones. Figure 2-16 shows average dark adaptation curves as measured with six test flashes of different wavelengths (Bartlett, 1965). The breaks in the curves, centered around 10-15 minutes, and the subsequent drop in thresholds, show the transition between the cones and rods. The extreme red, R_I, does not clearly show a transition from cones to rods, and it is believed that the entire function of R_I reflects cone activity solely. A practical application of the eye's response to the long wavelengths is in the use of red illumination or red goggles to preserve the dark adapted state. Refer again to Figure 2-15 and note that the function of the rods does not extend beyond approximately 675 nm. However, since the rods are not sensitive in this region, they will adapt to the dark as if there were no light present. Thus, when it becomes necessary to see in the dark, the rods are already adapted and immediate night vision will not be impaired.

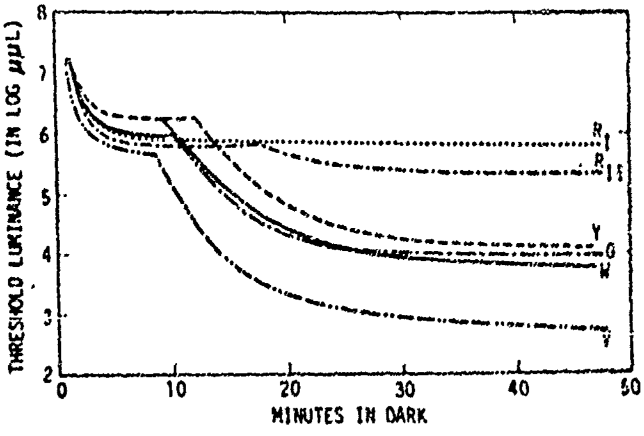


Figure 2-16. Average Dark-Adaption Curves as Measured with Six Different Colored Flashes

(From Bartlett 1965)

R_I - Extreme red, lower wavelength limit at 680 nm

R_{II} - A band between 620 and 700 nm, peaking at 635 nm

Y - A band between 555 and 620 nm, peaking at 573 nm

G - A band between 485 and 570 nm, peaking at 520 nm

V - A band with no wavelength longer than 485 nm

W - The full spectrum of wavelengths

There are several stimulus factors that affect dark adaptation, including: wavelength of the test flash (illustrated in Figure 2-16), the brightness of the adapting light, and the duration of the adapting period. The effects of the latter two variables are discussed below.

Luminance of the Adaptation Light. Prior to measuring the length of time necessary for complete dark adaptation, subjects are normally required to fixate upon an adapting light for a standard length of time. As the luminance of the adapting light decreases, the time required for complete dark adaptation decreases.

Duration of the Adaptation Period. The relationship between adaptation duration and the time required for complete dark adaptation is clear: the shorter the pre-adapting duration, the sooner dark adaptation is complete (Chapanis, 1949).

These two effects can be reciprocally manipulated in that within certain limits the same effect can be produced by a dim pre-adapting light presented for a relatively long time, or by an intense flash presented for a short time.

2.4.3 Light Adaptation

The phenomenon of light adaptation may be considered to be the opposite of dark adaptation. If the eye is presented with a light of a different intensity than that to which it was previously exposed, it immediately begins a process of either light or dark adaptation, depending on whether the second light was more or less intense than the first. In terms of the photochemistry of vision, this may be thought of as an attempt to reach a steady-state value of bleached photopigment. Light adaptation is of great importance to the understanding of the underlying chemical and neurophysiological processes of vision, but is of lesser practical importance than dark adaptation. The importance of light adaptation is noted occasionally in everyday life, as when emerging from a darkened theater into bright sunlight. The immediate impression is one of heightened brightness, in which it is difficult and sometimes painful to fixate on objects or to keep the eyes open. The effect dissipates at a very rapid rate, in comparison with the rate of dark adaptation. Investigators have employed numerous techniques to study effects during light adaptation, and the time course of adaptation depends greatly on the method employed. Perhaps the simplest method is to describe light adaptation in terms of the apparent brightness of a light presented to a dark-adapted eye for different lengths of time. The apparent brightness of this adapting light is determined by requiring the subject to adjust the brightness of a light presented to the other eye (which was not in the dark) until a match is achieved. When measured in this fashion, light adaptation is virtually complete after 1-3 minutes. For a discussion of other procedures, see Bartlett (1965).

2.4.4 Glare

A glare source may be defined as a source of light sufficiently brighter than the eye's level of adaptation so that annoyance, discomfort or loss in visual performance and visibility occurs. There are two types of glare: direct glare, caused by light sources in the visual field, and reflected or specular glare, caused by high intensity reflections from glossy surfaces. Glare causes an inhibition of the retinal receptor cells and the surroundings are perceived to be dimmer than they would otherwise appear. Glare destroys dark adaptation, and the length of time vision is impaired is dependent upon the intensity of the glare source as well as its duration.

McCormick (1970) reported a study in which subjects viewed test targets with a glare source of a 100-watt inside-frosted tungsten filament lamp in various positions in the visual field. The test targets were parallel bars varying in size and target-to-background contrast. The source of glare was varied in position, in relation to the direct line of vision, i.e., 5°, 10°, 20°, and 40° from the line of vision. The results were presented as the effect of glare on visual performance, shown as a percentage of the visual effectiveness possible without the glare source. It was shown that at a visual angle of 40°, visual effectiveness was 58%, and at an angle of 5°, visual performance was reduced to 16%.

Morgan et al. (1963) listed several methods to reduce the effects of both direct and reflected glare. Direct glare may be reduced by: (1) avoidance of bright light sources within 60° of the center of vision; (2) use of shields, hoods, and visors to keep direct light from the observer's eyes; (3) use of indirect lighting; and (4) use of several low-intensity light sources rather than one high-intensity light source. Reflected glare may be reduced by: (1) use of diffuse light; (2) use of dull, mat surfaces rather than polished surfaces; and (3) arrangement of direct light sources so that the viewing angle to the work area is not equal to the angle of incidence from the source.

2.4.5 Flashblindness

Flashblindness may be defined as a temporary loss of vision following exposure to an intense flash of light, from which an afterimage develops. The afterimage is perceived as a bright area, which persists for some time after the flash, and is the same size and shape as that of the flash field. The afterimage does not have to disappear entirely in order for the observer to perceive a target; the extent to which it must decay depends upon target characteristics. The decayed afterimage may be likened to a veil, in that the observer feels he is "looking through" it to perceive the target.

The incapacity and recovery from a flash must be measured in terms of some specific visual task, and thus will vary in duration according to the nature of the task.

Several military situations in which flashblindness could occur include flashes from projectiles, tracer bullets, incendiary weapons, enemy anti-aircraft lights, missile motors, and nuclear explosions (Jayle et al, 1959). Several parameters affect recovery time from flashblindness; these may be divided into stimulus and task/observer variables.

2.4.5.1 Stimulus variables

Flash intensity. In general, as the intensity of the flash increases, the recovery time from the flash increases.

Flash duration. The duration/recovery time relationship is similar to the intensity/recovery time relationship, i.e., the longer the flash duration, the longer the recovery period.

2.4.5.2 Task/observer variables

Target luminance. In general, visual reaction time will decrease to a minimum value with an increase in the luminance of the target.

Target size. As the size of the visual angle subtended by the target increases, recovery time will decrease.

Adaptation level of the eye. With an increase in the adaptation level of the eye, recovery time will increase.

The effects of flash intensity, flash duration, and adaptation level of the eye can be well predicted from a knowledge of certain photochemical mechanisms of the eye. This area is outside the realm of this book; however, should the reader wish to pursue the subject, see Graham (1965c), and Cornsweet (1970).

Miller (1965a) noted that recovery times for the detection of various kinds of targets and levels of target luminance may be generalized by specifying the equivalent field illuminance for threshold of the targets. The equivalent field illuminance is the retinal illuminance at which a target can be detected when viewed against a uniform field. In addition, she found that recovery time is related to the afterimage brightness decay, which is a function of the amount of bleaching of photopigment. The afterimage reduces perceived contrast in much the same manner as the addition of a uniform luminance over the display. Among many other sources on the effects of flashblindness on visual performance are Hill and Chisum (1962), Severin et al. (1963), Fry and Miller (1964), Brown (1964 a,b), and Miller (1965b).

There are methods which may lessen the degree of flashblindness. Jayle et al. (1959) recommended closing of one eye or lateral fixation in the external field of vision to protect against vision impairment.

The use of filter goggles has also been suggested. A trade-off exists with goggle usage, however. The greater the density of the goggles, the greater the protection afforded; yet, if the available light is low, dense goggles would seriously impair visual performance. Although other protective devices are under development, there is no reliable operational device at this time to prevent temporary flashblindness.

2.4.6 Critical Fusion Frequency (CFF)

This section discusses an important aspect of the human visual response to temporal variations -- namely, the perception of flicker. An understanding of the variables affecting flicker is important because of their relevance to later discussions of certain display parameters. The study of flicker is a means of determining the temporal acuity of the visual system. As in studies of spatial acuity, the procedure has traditionally been to employ square wave stimuli -- that is, stimuli that alternate between two levels of intensity in an abrupt manner. When a series of equally spaced flashes of light is presented, the perception of flicker is likely to occur. If the frequency of alternations is increased, there is a point at which the separate flashes will not be perceived, and a steady sensation of brightness will occur. The point at which flicker ceases to occur is known as the critical fusion frequency (CFF). Unlike many other threshold measures in psychophysics, the CFF can be specified quite precisely for a given set of conditions. There are, however, several parameters that have a strong effect on the CFF. The most important of these parameters are reviewed below. For a discussion of other variables that have been studied (e.g., surround luminance, monocular vs. binocular stimulation, duration of exposure) see, for example, Brown (1965a).

The intensity of the flashing light is probably the most important determiner of the CFF. The CFF can range from 60 Hz at very high luminance levels, down to less than 10 Hz at scotopic levels of stimulation. Figure 2-17 shows this relationship for a 19° stimulus, and for each of seven stimulus wavelengths. The abscissa is scaled in terms of retinal illuminance, which is merely the product of stimulus luminance and pupil diameter (see Table 2-II). It is seen that in the photopic region there is an approximately linear relation between CFF and log illuminance over a considerable range, and the relationship is largely unaffected by the color of the stimulus. At low illuminance levels, the rod-cone break is evident, and wavelength factors become important.

Another variable of importance is the size of the stimulus. A number of studies have shown that the effect of increasing the stimulus size is to enhance the perception of flicker. For a range of 1° up to about 50°, it has been found that there is an approximately linear relation between CFF and log stimulus area (Brown, 1965a).

The retinal locus of stimulation has been studied by numerous investigators, with respect to the CFF. It is not easy to summarize the

results, as several factors interact to determine the nature of the relationship. At low test luminances, flicker is perceived at higher flash rates in the periphery, while the foveal region is more sensitive at high luminances. The effect is further complicated, however, by the size of the stimulus. For very small stimuli (e.g., 12 minutes in diameter), foveal CFF's are usually higher, while for test fields above about 2°, peripheral CFF's are higher. For a summary of several studies, see Brown (1965a).

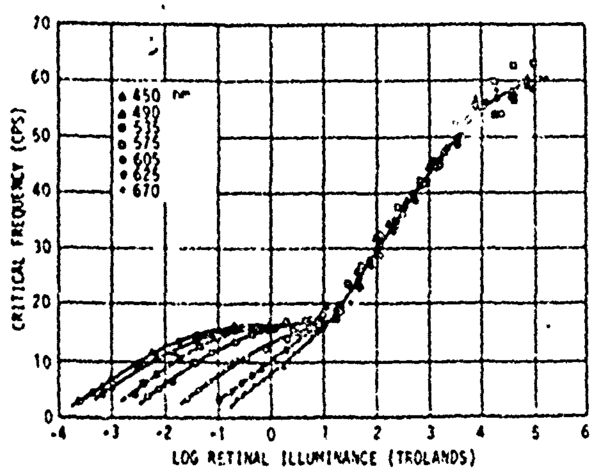


Figure 2-17. Relationship Between CFF and Log Retinal Illuminance, for Seven Wavelengths. (From Hecht and Shlaer, 1936).

Although the most common temporal pattern used in flicker experiments consists of equal light-dark intervals, a wide variety of light/dark ratios has been investigated, along with different waveforms such as sawtooth patterns, etc. For a given stimulus luminance, as the light/dark ratio changes, the average luminance of the display changes as well. To compensate for this change, the luminance of the stimulus may be increased or decreased, so that the average display luminance remains constant. In studies where such a procedure is followed, the usual finding is that as the light/dark ratio increases the CFF decreases. When the average luminance changes along with the light/dark ratio, the effect is more complex. The issue is further complicated by other variables that also have an effect, such as area of the test stimulus. It has been argued, however (Cornsweet, 1970), that many of the studies that investigated some aspect of the temporal waveform were unnecessary, in that the results could have been predicted from an understanding of the modulation transfer function (MTF) of the human visual system. The last sections of this chapter present a brief discussion of the application of Fourier analysis techniques to an understanding of the properties of the visual system.

2.5 Color Perception

In section 2.1.2 the topic of color was discussed in terms of the physical correlates of the psychological dimensions, hue, saturation,

and intensity. This section deals with some of the parameters that affect color perception. One source for a further treatment of certain topics of color perception, including a discussion of some physiological data, is a publication by Sheppard (1966). Other more comprehensive sources include Burnham et al. (1963) and Wyszecki and Stiles (1967).

2.5.1 Color Discrimination

We learn from early childhood that different hues are called by different names. Cultural influences dictate to a great degree the verbal distinctions made between different hues. For example, some tribes in Australia have only three color responses: one for red, purple and orange, one for white, yellow, and green, and another for black, blue, and violet. (Graham, 1965b). Occupations also influence the variety of color names we employ; an artist is likely to have a much larger repertoire of color labels than for example, an engineer or truck driver.

Many researchers have determined hue discrimination threshold curves. The thresholds are usually derived by determining the magnitude of the wavelength difference between a standard stimulus and a test stimulus which an observer can discriminate 50 percent of the time. Although the results differ somewhat between studies, the major characteristics of the data may be anticipated by an examination of the spectrum. The minimum thresholds appear in two regions, namely where there is a rapid change of hue. In the yellow region, where the color appears redder on one side and greener on the other, and in the blue-green region where it appears greener on one side, bluer on the other, minimum discrimination thresholds may be anticipated. The threshold is much lower when the task is to discriminate between hues rather than to name colors differentially. In other words, the observer is able to perceive hue differences when he cannot report different color names. Figure 2-18 illustrates the differential thresholds for hue discrimination across the visible spectrum. Saturation discrimination, to a degree, also varies with wavelength, but not to the same extent as hue discrimination. It has been determined that red or blue contain more noticeable different saturation steps than yellow, orange, or yellow-green. This, of course, is almost the reverse of what has been found for hue discrimination.

The correspondence between wavelength and hue is not always invariant. Except for discrete wavelengths along the spectrum which do not vary (i.e., yellow, 572 nm; green, 503 nm; and blue, 478 nm), all colors when increased in intensity will shift slightly towards either blue or yellow. This phenomenon is known as the Bezold-Brucke effect (Geldard, 1953). Intensity may also affect the saturation of a colored stimulus, as well as its hue. If the intensity of a monochromatic light is increased or decreased from its optimal level, the saturation of that light decreases (Osgood, 1953).

There are also observer variables which may affect color perception. The following variables are the major ones (Rusis, 1966):

Individual Differences. As mentioned previously, not only culture but occupations affect color perception, and individuals vary widely in

their ability to perceive color. This variability appears to be highly dependent on the individual's observational attitude.

Learning Effects. An observer is able, with practice, to increase considerably the number of colors he is capable of discriminating. However, if the skill is not used, it is quickly lost.

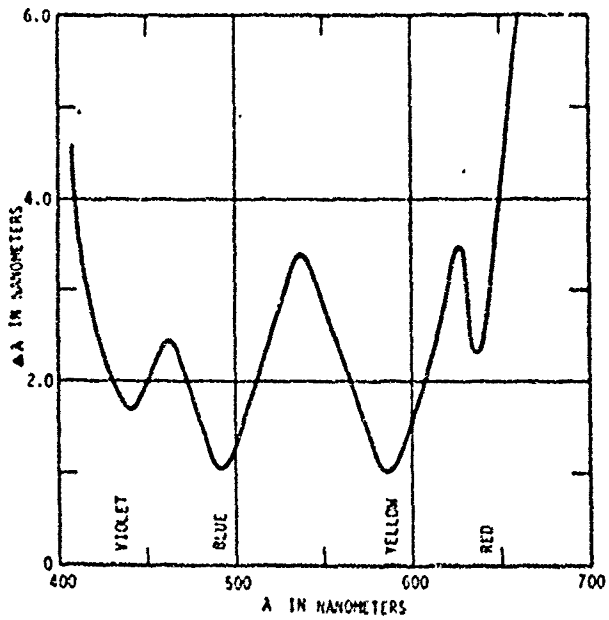


Figure 2-18. Wavelength Discrimination. The Change in Wavelength Which Can be Just Detected (Δλ) is Plotted as a Function of Wavelength (λ). (From Geldard, 1953).

2.5.2 Environment and Color

Some effects on color perception result from parameters within the environment other than those pertinent to the individual observer. The major considerations are:

Stimulus Size. In general, the larger the visual angle subtended by a stimulus, the brighter the perceived color. In the case of targets subtending very small visual angles, an achromatic perception (i.e., without hue) may result (Rusis, 1966).

Stimulus Distance. Because of atmospheric scattering, relatively dark objects typically appear bluish in the distance, while relatively bright objects appear to look orange or reddish (Burnham et al., 1963).

Time. The amount of time normally required for a steady light to elicit a color percept is between 0.05 and 0.2 second, which is related to "critical time" or the integration time of the eye. After the color

response has built up to maximum strength, there is a slight decline in response level until a plateau is reached. It takes somewhat less time for maximum stimulation to be reached for red than green, and less for green than blue (Burnham et al., 1963).

Color Contrast. There are color changes which occur as a result of color contrasts between adjacent stimuli. These include the following relationships: (1) An object with a highly saturated color near an object of the same hue with low saturation will appear more saturated, while the latter will appear less saturated than it actually is. The object with less saturation may appear achromatic or of the complementary hue to the more saturated object. (2) Objects near each other with complementary hues will both appear more saturated than if they were viewed separately. (3) Objects near each other with noncomplementary hues (e.g., red and yellow) usually appear more different in hue than if viewed separately. (4) Two colored areas separated by sharp contours appear to be more highly saturated and brighter than if they are separated by poorly defined contours. (5) High brightness contrast will reduce apparent hue contrast, while equal brightnesses tend to maximize hue contrasts. Rusis (1966) cited Gustafson (1960) as specifying that "the brightness contrast between any two colors should be at least 75 percent in order to keep discrimination errors below 1 percent."

Color Constancy. Under conditions of low illumination, or when a chromatic illumination is present (such as red lighting in a radar room), colors of familiar objects often are perceived to be the same as they appear under white light. For example, a green wall at night appears grey, but may be perceived as being green, if it is familiar to the observer.

Angular Limits. Because only the cones transmit color information, and are centrally located on the retina, color discriminability is restricted. Rusis (1966) after Lopatin (1956) described the angular color perception limits for both horizontal and vertical vision (see Table 2-V). These limits can be extended by allowing more head movement freedom for the observer.

TABLE 2-V

Horizontal and Vertical Angular Limits for Several Colors

Color	Angular Limits	
	Horizontal	Vertical
Green	60°	40°
Red	60°	45°
Blue	100°	60°
Yellow	120°	95°
White	180°	130°

2.6 Distance Perception

Inherent in the course of target acquisition and interdiction is the pilot's capability of distance perception. The cues we use in judging distances are learned early and are employed so frequently that they become relatively unconscious. The following are the major cues for distance perception, divided into monocular and binocular cues.

2.6.1 Monocular Cues

Relative Size. Targets of similar actual size, viewed simultaneously, will be judged to be at different distances from the observer if one appears larger than the other. The perceived distance between the observer and a target is dependent on the disparity between the real size and the retinal image. Therefore, the greater the difference between retinal and judged size, the greater is the distance perceived. Note that this cue can lead to a false judgement of distance, when the observer incorrectly judges the size of a particular object. For example, if the observer saw a 747 aircraft sitting on a runway, and mistakenly thought it to be a smaller aircraft, perhaps a 707, he would then judge his distance to the aircraft to be closer than it actually was.

Aerial Perspective. Distance perception is partly dependent upon atmospheric conditions. The air always has some particles of water and dust even on "clear" days. The particles (aerosols) obscure the outlines of distant objects. During fog conditions even relatively near objects appear indistinct and seem to "loom up" as they are approached. In the desert, however, where the air is clearer and drier, relatively distant objects appear quite distinct and are perceived as being much nearer than they actually are.

Linear Perspective. Sets of objects of similar size, equidistant apart, appear to converge as they near the horizon; for example, telephone wires seem to approach each other in the distance.

Lights and Shadows. These cues are often more an indication of depth and contour than distance. The associations are dependent on our adaptation to overhead light sources. Assuming overhead lighting, convex surfaces are shaded in the lower portion and concave surfaces in the upper portion. As a cue to distance, the shadow cast by one object upon another indicates which object is the more distant. However, it is necessary to know the source or direction of the light.

Interposition. When two objects are observed, one positioned in front of the other, the more distant object is cut off from complete view by the nearer one.

Motion Parallax. This cue for distance is used under two different circumstances: when the observer is moving and when he is stationary. In situations such as flying in an airplane, objects near the aircraft seem to move rapidly past while distant objects appear to move quite slowly or not

at all, the velocities being a function of the object's real distance. When the observer is stationary the parallax occurs by moving the head. When the head is moved at least 15 cm to the right or left, nearer objects move in the opposite direction from the observer's head movement, while relatively distant objects move in the same direction as the observer.

Texture. When observing a plowed field, for example, irregularities in the ground are very evident near the observer, but seem to smooth out in the distance. In addition, the lines of the field (if horizontal) will grow denser in the distance.

Accommodation. Accommodation may be considered a nonvisual cue because the distance information arises not from a visual sensation but from a kinesthetic sensation (i.e., muscle contraction). To obtain a clear image on the retina, the lens of the eye must be focused for the distance of the object from the observer. If the object being viewed is more than approximately six meters away, the ciliary muscle is relaxed. As the object becomes closer the muscle must contract to maintain focus. The cue depends on the degree of contraction and is obviously a weak distance cue. It is not reliable as a distance cue beyond about two meters (Graham, 1965b).

2.6.2 Binocular Cues

Binocular Disparity. Because the eyes are approximately 6 cm apart, they do not see exactly the same aspects of an object. The closer the object is, the greater the disparity of the images on the two eyes. The result is stereoscopic vision, that is, the perception of objects in three dimensions. The topic will not be covered in any detail here because binocular disparity is too small to be perceived beyond about 450 meters (Graham, 1951). Thus, it is relatively unimportant to problems of air-to-ground viewing.

Convergence. As with accommodation, convergence is only a secondary (kinesthetic) cue. In order to cause the image of a near object to fall on the foveal regions of both eyes, the eyes must rotate inward toward each other. The closer the object, the more "cross-eyed" one must be. Again, convergence is effective only for objects a few meters from the observer.

2.7 The Modulation Transfer Function (MTF) of the Eye

In recent years there has been considerable interest in a different technique for studying the response of the human visual system. This technique has relevance for studies of form discrimination, visual acuity, contrast sensitivity, relative motion, and thus target acquisition. As will be seen in later chapters, it also has great relevance to the problem of specifying atmospheric transmittance, and image quality on a display. The technique is useful in helping designers to decide whether certain changes in sensor or display characteristics will actually result in an improvement in visual perception. This technique, called linear systems analysis, involves estimating the modulation transfer function (MTF) of the visual system (also referred to as the sine wave response function). It represents

an application of Fourier analysis techniques to the study of human vision, and is considered an effective descriptive and predictive tool. Essentially, it is based on an analysis of how the visual system responds to spatial sine wave intensity patterns of different frequencies and amplitudes.

2.7.1 Determination of MTF

Once it has been determined what response the visual system makes to a range of frequencies, it is possible to calculate a predicted response to patterns of much greater complexity. This section will discuss the fundamentals of the MTF. The following sections will briefly review some of the procedures by which investigators have tried to determine the human MTF, and some of the experimental results obtained. Some examples of the application of the MTF, discussing certain perceptual phenomena that can be predicted with this technique, along with instances where this approach has not been satisfactory are noted.

The concept of the modulation transfer function is not new. It has been used for some time to describe the temporal properties of certain systems (e.g., audio equipment). More recently, it has been applied to the analysis of spatial systems as well, as in evaluating the overall quality of an optical instrument, or determining the amount of image degradation produced by a certain component. In the last decade there has been considerable interest in extending this approach to the human being. The interest is not simply in studying the optical properties of the eyeball, but in extending well beyond that level so that the system "output" under study is the perception itself, which is not directly observable. This makes the job of specifying the MTF considerably more difficult, as will be seen.

The reason for the usefulness of the MTF may be understood by reference to the concept of Fourier analysis. Fourier analysis as it applies to spatial patterns may be described as follows. (For the reader wishing a rigorous treatment of this subject, see for example Goodman, 1968. For a qualitative -- i.e., non-mathematical -- understanding, an excellent source is Cornsweet, 1970.) Consider a test pattern consisting of alternating light and dark vertical stripes, Figure 2-19a. Such a pattern, called a resolution grating, is sometimes used to test visual acuity. Starting at the left edge of the pattern (a dark stripe), the intensity would be at a low value for some distance (perhaps 20 arc minutes at a certain viewing distance), then would abruptly rise to a higher level for another 20 arc minutes, then back down, and so on. Thus, the graph representing such a distribution would be a series of square waves, Figure 2-19b. In this example, the waveform is regular; in the case of another pattern (for example, a terrain photograph) the waveform could be very irregular. Regardless of shape, as a result of Fourier's theorem that waveform is known to be composed of a number of sine waves of various amplitude, frequency, and phase relationships, which are added together. By means of Fourier analysis it is possible to determine the characteristics of these sine waves, and thus completely describe the pattern in terms of its sine wave components.

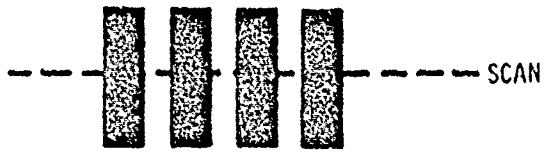


Figure 2-19a. Test Pattern Resolution Grating

Figure 2-19b. Scan Response

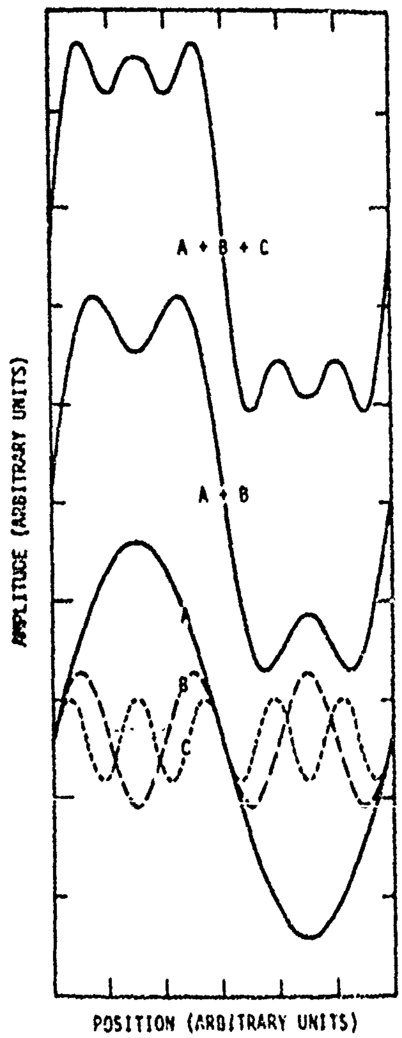


Figure 2-19c. The Addition of Sine Waves to Synthesize a Square Wave. If the Fundamental Frequency of the Square Wave is F, then the Frequencies of the Sine Waves are F, 3F, 5F, 7F,..., and Their Amplitudes are A, A/3, A/5, A/7,... (From Cornsweet, 1970).

As an example, Figure 2-19c shows how a number of sine waves may combine to produce a square wave. To obtain a perfect square wave, an infinite number of sine waves must be added together, related to each other. In general, for any pattern having sharp transitions between light and dark areas, high-frequency components are necessary. Without these high-frequency components the corners of the waveform are rounded, and the transition between a light and dark area is more gradual.

To predict how a system will respond to a pattern, it must be known how the system responds to those sine wave components which comprise it. The MTF is simply a means of describing the sine wave response of the system across a range of frequencies. For example, to determine the MTF of a lens, the lens would be presented with a series of sine wave gratings. Compared to a square-wave grating, these stripes would not have sharp borders; instead, there would be a gradual change from a dark stripe to a light one. The modulation of each grating can be determined by measuring its luminance at the brightest point (L_{max}), and at its dimmest point (L_{min}). Modulation is then defined as:

$$M = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

The procedure, then, is to measure the modulation of the original grating, and the modulation of the grating as imaged by the lens. The modulation transfer for that particular frequency is then expressed as the ratio: M_{image}/M_{object}.

As the frequency of the grating changes, the modulation transfer is affected. For very wide stripes (i.e., low spatial frequency), the modulation transfer would be at its maximum value of 1.0, or close to it. It is at the higher frequencies where the aberrations of the lens start to have serious consequences for the image. When the object grating is fine enough (its frequency is high enough), the resulting image will just be a uniform shade of gray, and the modulation transfer will be zero. Thus, if the modulation transfer of that lens were plotted as a function of spatial frequency, the function would begin at 1.0, and gradually drop to zero. This normalized function is called the MTF.

Figure 2-20 shows how the MTF can be used to predict the response of a system (in this case) to some pattern other than a sine wave. Figure 2-20a shows the intensity distribution of a particular pattern. The left part of the pattern being described is uniformly light, up to a point at which it abruptly begins to get darker. It continues to darken for a while, then abruptly stops, so that the right hand portion of the pattern is uniformly dark. Figure 2-20b is a result of a Fourier analysis on the waveform shown in Figure 2-20a. This figure shows the relative amplitudes of all the sine waves necessary to produce this waveform. It can be seen that a sine wave of some amplitude is required at almost every frequency. Figure 2-20c shows the MTF of the lens being considered. In Figure 2-20d, the amplitude

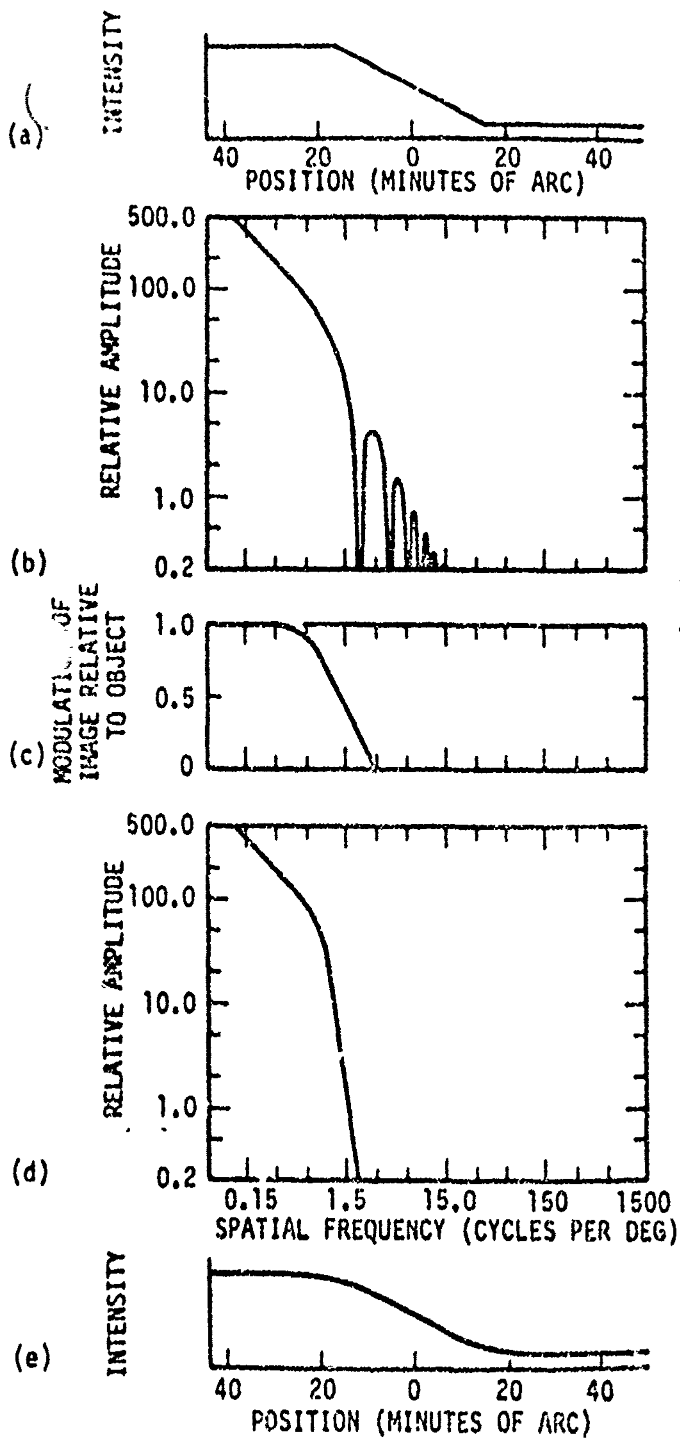


Figure 2-20. How the MTF is Used to Describe the Image that a Lens will Produce. In (a) the Intensity Distribution of the Object is Plotted. The Fourier Spectrum of the Function in (a) is Plotted in (b). The MTF of the Lens is Shown in (c). The Spectrum of the Image is Shown in (d), Which is the Product of (b) and (c) at Each Spatial Frequency. The Resulting Intensity Distribution of the Object is Presented in (e) (From Cornsweet, 1970).

of each sine wave in 2-20b has simply been multiplied by the transfer factor for that frequency, as presented in 2-20c. Thus, Figure 2-20d shows the amplitude spectrum of the image as it is produced. High frequency components are responsible for sharp corners, and since the MTF drops off at high frequencies, this is the result to be expected.

This section has shown how the MTF may be calculated for an optical system, and how it may be used to predict how that system will resolve various patterns. The following section shows how the MTF can be obtained for the human visual system. The use of the term visual transfer function will be restricted to the description of a linear system, or a system operating in a linear range. The human visual system is not linear over a wide portion of its operating range; that is, the magnitude of the output is not linearly related to the magnitude of the input. However, within much of the range of interest for target acquisition the approximation of linearity can be used.

2.7.2 Human Visual Response to Sine Wave Patterns

To determine the sine wave response of the human visual system is more complicated than the procedure described. The reason for this is obvious: it is not possible to employ a photometer and measure objectively the luminance distribution of an object as it is perceived by the observer. Instead, it is necessary to employ more indirect procedures. Several different kinds of procedures have been employed. The results have been in general agreement, the greatest sensitivity to spatial frequencies usually occurs in the region of 3-6 cycles/degree.

The details of the experiments and the stimuli employed will not be explored here; instead, it is sufficient to note that a transfer function is eventually obtained which has the form shown in Figure 2-21. Again, note that there is a decline in resolution at both extremes of the spectrum, with a maximum occurring at around 6-9 cycles/degree; this is equivalent to about 1 line/mm at a viewing distance of 14 inches.

2.7.3 The Uses and Limitations of the Human Spatial MTF

The above discussion of attempts to derive a spatial MTF for the human visual system has been simplified in a number of respects. There are assumptions to be met in order for the use of the MTF to be valid (cf. Cornsweet 1970, for a discussion of linearity, isotropy, and homogeneity). The most troublesome assumption is that of linearity, for there is much evidence that visual perception results from the operation of a highly nonlinear system. By nonlinear we mean that the magnitude of the output (the perception) is not related linearly to the magnitude of the stimulus that gives rise to it. Instead, the relationship is more nearly a logarithmic one. The issue is complicated, and the fact that it is beyond the scope of this chapter to explore it does not mean to imply that it is unimportant. Of course, the precise shape and positioning of the MTF curve depend on a number of parameters (e.g., average display luminance, accommodation distance), and a

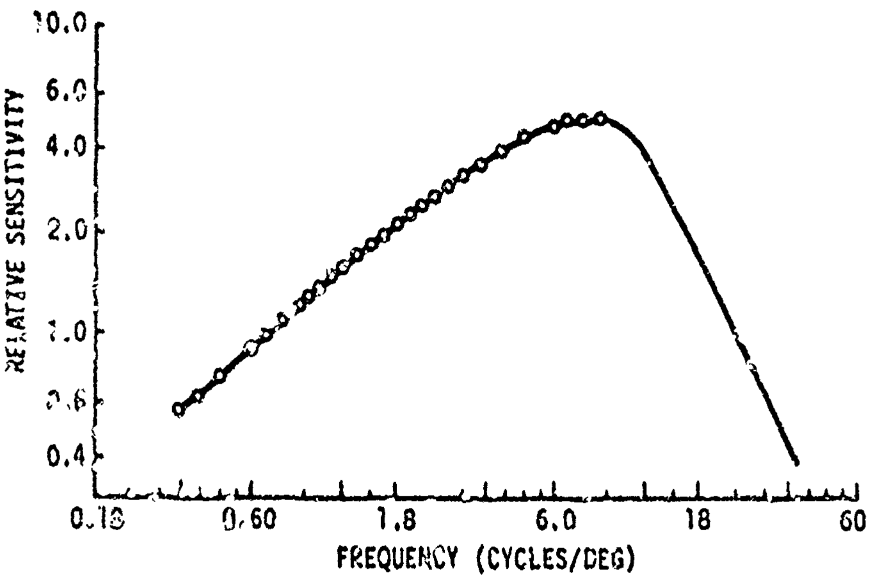


Figure 2-31. A Transfer Function for the Human Visual System. The Circles are Data Points from a Contrast Matching Experiment; the Region Without Circles is Based on Threshold Measures (From Cornsweet, 1970).

great deal of work is still required to explore such parameters and to optimize the technique. Nevertheless, at our present state of knowledge enough is known of the general form of the human MTF to enable us to predict some interesting perceptual phenomena.

Border contrast enhancement is predicted by the fact that the MTF drops off at low spatial frequencies. Figure 2-22 shows the steps in predicting the output for the two patterns represented in Figure 2-22a. The figure on the left, which would be a light stripe on a darker background, is similar to the one on the right in that both have sharp "corners." The difference, as may be seen in Figure 2-22b, is in the low frequency region; the curve on the right has areas of gradual change, represented by low frequency sine wave components, while the corresponding regions on the left hand curve exhibit no change -- i.e., have an infinitely low spatial frequency. The human MTF, shown in Figure 2-22c, shows that both high and low frequencies will be attenuated. As we have seen, the sharp corners will be rounded due to the high frequency cutoff as is shown to be the case in Figure 2-22d. What is also shown is that the differences between the two curves are almost entirely eliminated, since those differences exist in a frequency range to which the visual system is not responsive. This prediction is perceptually correct; the two patterns do in fact look identical. And as can be seen in the left half of Figure 2-22e, due to the low frequency attenuation the regions of greatest brightness difference (border contrast enhancement) are in the regions of abrupt transition between intensity levels.

Another phenomenon the MTF predicts well is simultaneous brightness contrast. If a gray pattern is viewed against a black background, it appears lighter than it does if viewed against a white background. If the patterns are plotted and the usual analyses performed, it is seen that such a result is to be expected (Cornsweet, 1970).

There are also situations in which the predictions based on the human MTF fail. For example, with patterns such as those described in Figure 2-22e, subjects are not likely to report brightness differences between the center and the edge of the stripe. In other cases perceived differences, between regions separated by a border that appears sharp, are greater than they "should" be. There are several reasons for such discrepancies. In some cases, the conditions under which the MTF was obtained (e.g., brief flashes, low target contrasts) were too different from the viewing conditions employed in the evaluation. In other cases the predictions are upheld when the experimenter, in essence, asks the right questions; the subject's response repertoire and expectations sometimes limit the way in which he can describe what he sees. In other cases the nonlinearity in the visual system provides a strong barrier against accurate prediction. Work is progressing in the study of human visual nonlinearity, in the hope that by understanding the nonlinearity better, means may be devised for incorporating it in the prediction.

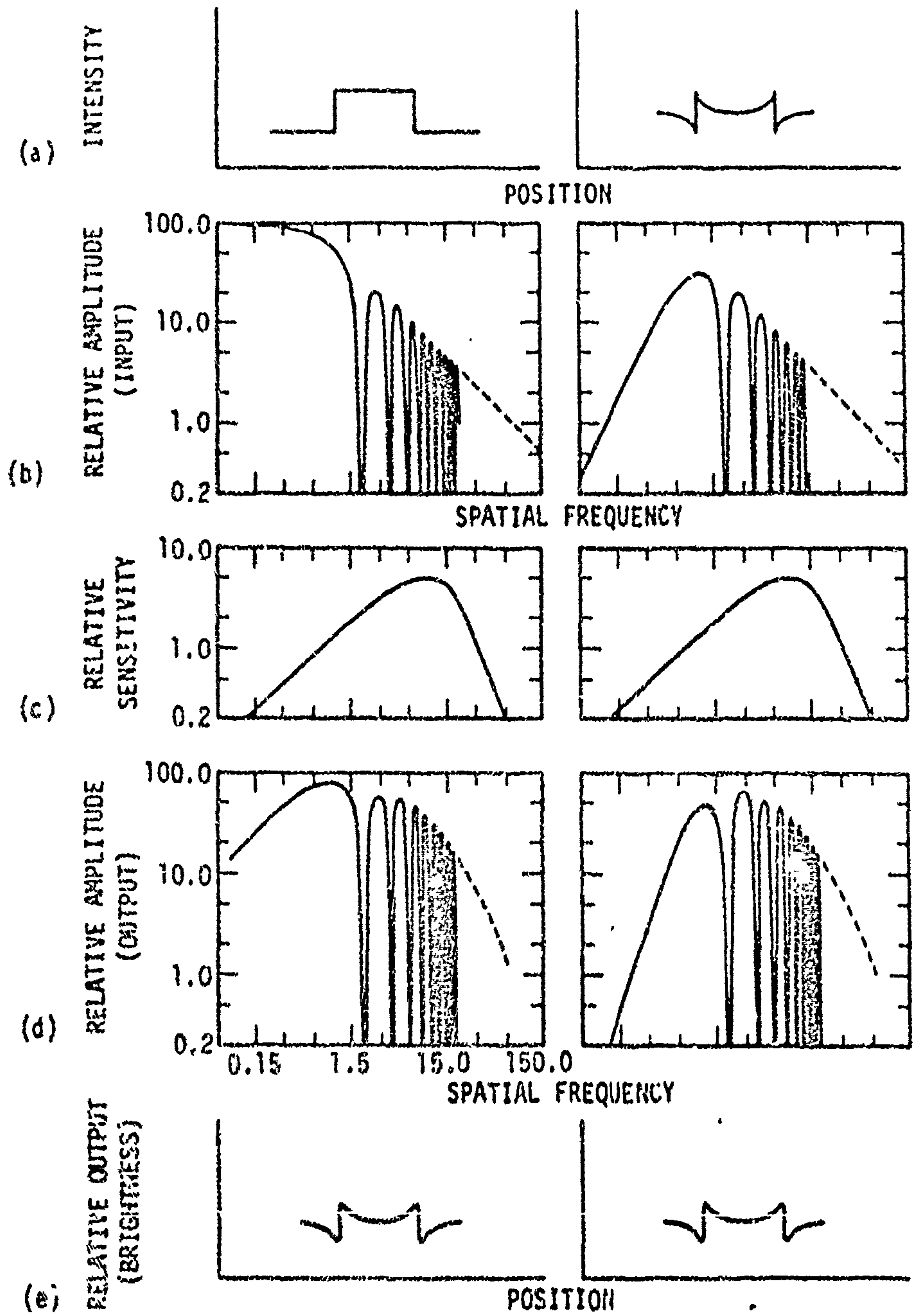


Figure 2-22. Calculation of the (Perceptual) Brightness Distributions that Should Result from the Intensity Distributions in (a). (From Cornsweet, 1970).

2.7.4 The Temporal Modulation Transfer Function (MTF)

The temporal frequency response for human vision can be determined in a manner analogous to that described for the spatial sine wave response. The eye's response to sine wave variations may then be used to predict the perception of complex temporal waveforms, again assuming linearity in the visual system. A considerable amount of work in this area has been performed by Kelly (1961). His procedure was to provide a large (60°) circular test field, uniformly illuminated, and with blurred edges. The luminance of this field could be varied as a function of time, in a sinusoidal fashion. The task of the subject was to adjust the amplitude of this variation (with the average level held constant) until it was barely large enough to be detected. The frequency of the variation was then manipulated by the experimenter, as was the average luminance level. (The data to be presented are actually in terms of average retinal illuminance, rather than luminance. Since an artificial pupil was used, however, there is a perfect correlation between the two measures). Figure 2-23 presents the results of this experiment, plotted in two ways. In Figure 2-23a absolute sensitivity is shown, as a function of temporal frequency. It may be seen that maximum sensitivity for high average luminances is around 25-30 Hz, and that the maximum occurs at lower frequencies as the average luminance is decreased. Another important feature of this figure is that all of the curves begin to coincide as the frequency increases. Thus, at a frequency of 50 Hz for example, the modulation amplitude required for the intensity variation to be perceived does not change -- it is the same for all the average luminances employed. Figure 2-23b presents the same data expressed as percentages, so that the values on each curve of Figure 2-23a have been divided by the average luminance represented by that curve. Presenting the data in this fashion demonstrates that in the case of low temporal frequencies it is necessary to increase the modulation as the average luminance increases, until the same percentage of modulation is attained.

These curves, except at the very low intensity levels, have the same general shape as the spatial sine wave response functions discussed in an earlier section; that is, they show a decrease in sensitivity to low frequency inputs as well as to high frequency inputs. A similar approach may now be taken to predicting behavior for more complex waveforms, provided the condition of linearity can be met. A further inspection of Figure 2-23a reveals that this condition has been met, for high temporal frequencies. As in our consideration of the spatial MTF, a system is operating in a linear range if the ratio of input to output modulation is constant, regardless of the average value. The fact that the high-frequency portions of all the functions in this figure fall on the same downward sloping curve indicates that the system is indeed linear for high frequencies, for regardless of the average luminance the threshold modulation at a given frequency remains fixed. At low frequencies, however, it is evident that the visual system is not linear. Because of the fact that a constant relative modulation is required at threshold, the system appears to undergo a logarithmic transformation at low frequencies (Cornsweet, 1970).

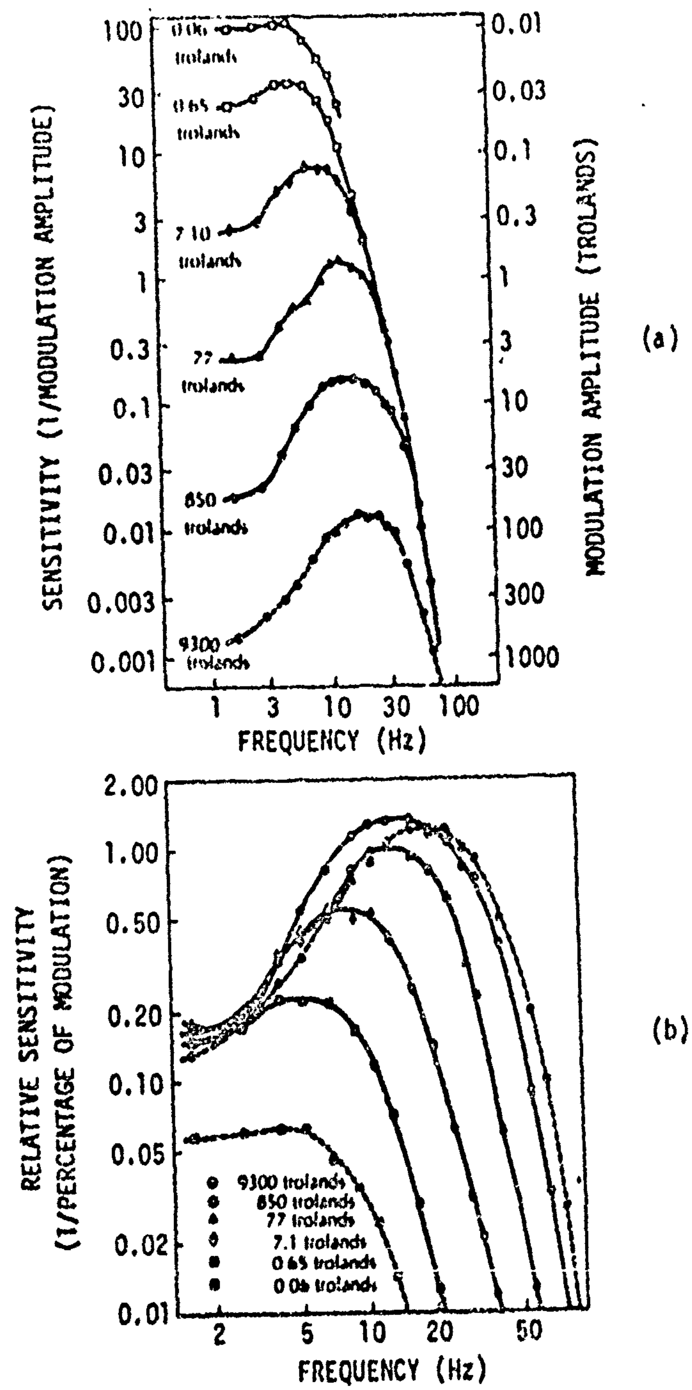


Figure 2-23. Temporal Sine Wave Response Functions, Plotted Two Different Ways. The Separate Curves are for Different Average Levels of Retinal Illuminance. (Figures from Kelly, 1961; Re-labeled by Cornsweet, 1970).

To illustrate how the temporal MTF can be used to predict the CFF for a square wave pattern, consider what happens to the input spectrum as the frequency of the square wave increases. The frequency of the fundamental sine wave component increases at the same rate, because it is identical to the repetition rate of the square wave. At the same time, the higher order harmonics, which as we have seen are multiples of the fundamental frequency, also increase (cf. Figure 2-19). But because of the sharp dropoff of the MTF at high frequencies, the contribution of the higher order harmonics drops to practically zero whenever the square wave pulse frequency approaches the fusion point. Thus, the CFF for a square wave is the same as that for a sine wave of equivalent modulation amplitude. For a further discussion of the application of Fourier techniques to the study of flicker, see Brown (1965a) and Cornsweet (1970).

Another instance where the temporal MTF can be used to predict a perceptual phenomenon is in the case of Bloch's law (also sometimes referred to as the Bunsen-Roscoe law). Bloch's law states that there is a reciprocity relationship between the intensity and duration of a flash, so that below a critical duration all flashes of equal total energy should have equal perceptual effects. In other words, Luminance x Time = Constant, for a square wave pulse. Bloch's law is an example of the temporal integration properties of the human visual system. The important quantity for perception is the time integral of the luminance, rather than the particular distribution of luminance with respect to time (again, this is true only up to a certain critical duration, which, in the case of threshold measures, is approximately 0.1 second). Another way to express temporal integration is by means of the Blondel-Rey law (Lloyd, 1973), which describes the relation between a just-visible flash of light, and a just-visible steady light:

$$L = L_{\infty}(1 + \frac{c}{t}),$$

where L is the threshold luminance for a steady light exposed for t seconds; L_{∞} is the threshold luminance for a steady light of infinite duration; and c is a constant equal to 0.21 second. It may be shown that with this formula, when t is below approximately 0.1 second, the product of L x t is very nearly a constant.

With respect to the MTF predictions, Cornsweet (1970) has shown that most of the difference between equal energy square wave flashes of different durations is in the high frequency components, which are strongly attenuated by the MTF. Therefore, up to some duration, all such flashes have very nearly the same output spectrum. As lower average luminances are employed, the MTF begins its sharp decline at progressively lower frequencies (Figure 2-23a), thereby increasing the temporal range of flashes that will all appear identical.

2.7.5 Applications of MTF to Target Acquisition

In summary, the use of the MTF holds a good deal of promise in the study of many problems in which the human visual response must be known.

It has limitations, and care must be taken to apply it properly (for example, by making sure the conditions under which the MTF was obtained are as similar as possible to those for which a prediction is being made). In addition, it should be noted that the MTF is not an explanatory tool; the underlying photochemical and neurophysiological mechanisms have been entirely excluded from this discussion. Nevertheless, it can predict certain classes of events. The MTF approach, applied to the analysis of prior experiments in the target acquisition field, may help to resolve apparent contradictions between different sets of data, or to suggest critical experiments that would resolve such contradictions. In addition, it may serve as a useful tool in helping designers to make certain decisions. For example, an engineer trying to decide whether one display would be better than another might determine that for a certain class of targets, two different levels of fidelity might in fact be indistinguishable when they go through the human visual system. Thus, in comparison with more traditional approaches to the study of visual acuity, the MTF has been shown to be a more comprehensive, predictive, and systems-oriented tool for studying the human visual response. Use of MTF in predicting target acquisition has not been done. Yet, as noted in the following chapters, we can determine some atmospheric MTF, sensor-display MTF and visual MTF. In theory, the probability of target acquisition should be the resultant combination of those MTF's.

CHAPTER THREE

TARGET AND ENVIRONMENTAL FACTORS

3.1 Introduction

Some of the most critical factors affecting target detection and recognition are those pertaining to the characteristics of the target and its background. The target's size, shape, color, and texture are of course primary to the task requirements. Background can be cluttered, simple, homogeneous, flat, mountainous, hilly, forested, grassy, bushy, farmland, with many or few man-made features. Environmental factors include the characteristics of the atmosphere as to its clarity, sun angle, the presence of smoke, haze, fog, dust, etc. When dealing with other than direct visual target acquisition, other target/background/environmental factors become important, such as the thermal signature of target and background, in the case of infrared sensors, for example. This chapter will consist of two major subdivisions: the first dealing with the target and background characteristics and the second half with the effects of the physical environment.

3.1.1 Sources of General Information

The best general reviews of the target and environmental factors influencing target acquisition are to be found in Middleton (1952) and in Erickson (1965). Middleton has an excellent chapter on the extinction of light and the alteration of contrast by the atmosphere. This book although getting somewhat dated does provide nomographs for predicting "sighting range" derived from the Tiffany data (Blackwell, 1946) and is still very useful to the practitioner and researcher. These nomographs take the ambient illumination into account, as well as the contrast of the target to its background, and the meteorological range. Erickson (1961 and 1965) provides the data needed to determine the probability of detecting the target in different types of terrain (1961). The 1965 report also takes motion, search geometry, cockpit obstruction, type of search, target type, surface reflectance, and clutter into account. There is also a discussion of simulator and field studies. Optical characteristics are discussed in a manner helpful to the operational types of personnel concerned with problems of target acquisition. Both Middleton and Erickson (1965) contain good bibliographies which can be used for finding additional data.

Other good general references are the series of papers entitled "Visibility" published in 1964 in The Journal of Applied Optics, by the Duntley group at Scripps Visibility Laboratory and in the Air Force Survey in

Geophysics No. 21 published by Penndorf, Goldberg and Lufkin in 1952. Both reports contain good atmospheric information, practical data for the designer and field user. The RCA Electro-optics Handbook is another source of atmospheric data useful in both direct visual and electro-optical sensor analyses.

3.2 Target/Background Variables

This section is concerned with the effects on target acquisition performance of variables associated with the targets, and with their background characteristics. Variables such as size and shape are specifically target characteristics. Others such as vegetation and clutter relate to the background; and some, for example, contrast and masking, are associated with both target and background characteristics. Although target features can be varied independently of the background, and vice versa, target detection and recognition depend on the interactive effect of both target and background variables. This relationship must be taken into account when considering the effects discussed.

The primary target/background variables; target size, contrast, masking, and terrain type, are among the most important and the most extensively investigated variables affecting air-to-ground target acquisition performance. Target size and shape for example, have been the subject of many laboratory studies, simulation experiments, and field trials. Target/background contrast and background clutter have been studied extensively in carefully controlled laboratory experiments. The relatively small amount of flight test data relating these factors to target acquisition reflects the difficulty of controlling and quantifying them under flight test conditions. Fortunately, the effects of vegetation and terrain type can be studied experimentally by high-fidelity simulation techniques and in field trials.

In this section the effects of target and background characteristics, and two secondary variables, angular velocity and motion are considered. Variables associated with both target and background interaction are then discussed and finally, environmental parameters such as atmosphere and illumination.

3.2.1 Target Size

In air-to-ground acquisition tasks, target size may be measured either in terms of actual ground size, or in terms of apparent size, defined as the visual angle subtended by the target at the observer's eye. Apparent size depends on the actual size of the target, the angle at which it is viewed, the range of the target, and the characteristics of the viewing system, if any, interposed between target and observer.

A target becomes capable of detection when its angular subtense exceeds the visual acuity threshold, but most targets are not detected until the angular subtense is considerably above threshold. This indicates that search problems are more important than visual acuity limitations in actual air-to-ground target acquisition (cf Chapter 5).

Work carried out by Jones and Bergert (1970), using simple two-dimensional targets in a terrain-model study, demonstrated that the angular subtenses required for both detection and recognition involving search were greater than when search was not required. The detection task involving search required an angular subtense almost twice as great as the corresponding threshold values. Required angular subtense values depended on contrast. For the 20% contrast level, targets had to subtend 2.7 minutes of arc for detection under search conditions and 1.4 minutes of arc under threshold (non-search) conditions.

Additional evidence that the angular size requirements of targets at acquisition are substantially higher than the acuity threshold comes from in-flight acquisition data reported by Moler (1962) and simulation data reported by Snyder and Greening (1963) under presumably medium contrast (20-50%) conditions. In both of these studies each target's major dimension subtended more than 10 minutes of visual arc at the median range of recognition. This agrees with Steedman and Baker (1960) who found that an angular subtense of at least 12 minutes of arc is required for the accurate recognition of complex forms under "high" contrast (>50%) and ideal viewing conditions.

The common laboratory finding that, other things being equal, larger targets are more readily detected and recognized than smaller ones (Boynton and Bush, 1957; Miller and Ludvigh, 1960) has been confirmed by field test and by high-fidelity simulation experiments. Whittenburg, Schreiber and Richards (1959b) studied apparent target size in a field test and found a positive relationship between size and identification probability. For small apparent sizes, up to about 25 sq. mils (a square mil being the polyhedral angle subtended by an area of one square unit at a distance of 1000 units), identification probability was highly related to size. Above this value, size had little effect. A field test carried out by Hicks and Moler (1966) also showed that large targets were more readily identified than small ones.

Rusis and Snyder (1965) used a motion picture simulation to investigate the effects of target size, measured in terms of the percentage of the film frame covered by the target at a fixed range of 1000 ft. (304.8 m.). They found that for small targets (average subtended angle 0.003 steradian) acquisition probability was significantly lower, and acquisition range shorter, than for targets of large apparent size (average subtended angle 0.089 steradian). Errors of omission and errors of commission were also significantly higher.

3.2.2 Target Shape

Several target acquisition studies have shown that targets of very similar size but differing in shape can give rise to substantial differences in performance. For instance, Moler (1962) and Snyder, Greening and Calhoun (1964) both found differences in recognition probability between military vehicles roughly equal in size, even when the targets were located in the same location and approached from the same direction. Similar results were found by Snyder and Greening (1963) when they compared recognition performance for rectangular parallelepipeds and for cubes of equal frontal area.

These performance differences are accounted for by differences in target shape. Laboratory findings (National Defense Research Committee, 1946) suggest that targets characterized by a relatively large length-to-width ratio are more difficult to detect than those that are more nearly square. These differences based on length-to-width ratio have not been confirmed by air-to-ground target acquisition field tests, however.

The shape of a ground target, in terms of aspect ratio (vertical to horizontal extension), is important in relation to aircraft altitude. A predominantly vertical target will, in the absence of masking effects, appear larger at low altitudes, whereas predominantly horizontal targets will subtend a greater angle when viewed from higher altitudes. These effects have been analyzed by Greening (1964).

3.2.3 Target Type

Target acquisition experiments normally involve a number of different types of targets, for instance, bridges, buildings, personnel and/or vehicles. Target type characteristics play an important part in determining acquisition performance where a detail is used in discriminating target type. Differences between target type acquisition data can be attributed to differences in size, contrast, the presence or absence of shape details, and in briefing, cues, and training of observers.

In one study, four different target types (segments of pipeline, road intersections, small areas of water, and petroleum storage tanks) were compared using a motion picture simulation technique. The results indicated that subjects paid more attention to gross characteristics of the target terrain cues, for instance the presence of a nearby road, than to the experimenters' target functional classification (Calhoun and Snyder, 1965).

Target classifications are of limited utility unless they also correspond to large differences in visual characteristics, such as size. This also was found in study of target type in which differences in acquisition performance were found for four different target types, categorized as trucks, jeeps, tents, and men (Snyder, Greening and Calhoun, 1964). Target size was the major determinant of acquisition performance in this study.

Familiarity with the target has an important effect on target identification, particularly when a number of different targets are situated close together. Thomas (1962) found that observers unfamiliar with the name of a particular target tended to maintain prolonged visual contact with it. They failed to detect other targets in the same area. Similarly, Whittenburg et al (1960a) report that lack of knowledge of the names and appearances of military objects is a major limiting factor in effective target identification. They recommended specialized training in the identification of enemy weapons, vehicles, and other types of equipment.

3.2.4 Multiple Targets

When a number of small targets are situated closely together, the effect is one of a target complex, rather than one of individual targets. Dukes and McEachern (1955) and Von Arsdall (1974) found that grouped targets were detected more often than ungrouped or single ones. If all the targets in the group are the same type, then identification of grouped targets is no more difficult than identification of a single target. However, interpretation problems may arise in the case of a heterogeneous group.

For instance, Whittenburg et al (1960a) report that placing a series of different targets less than 3 seconds flying time apart, tended to reduce identification scores. They suggest that this may have been due to a tendency for observers to "lock on" or fixate one target at the expense of others nearby. It appears therefore that the effect of grouping heterogeneous targets is to facilitate detection, but it also impairs identification of its individual members.

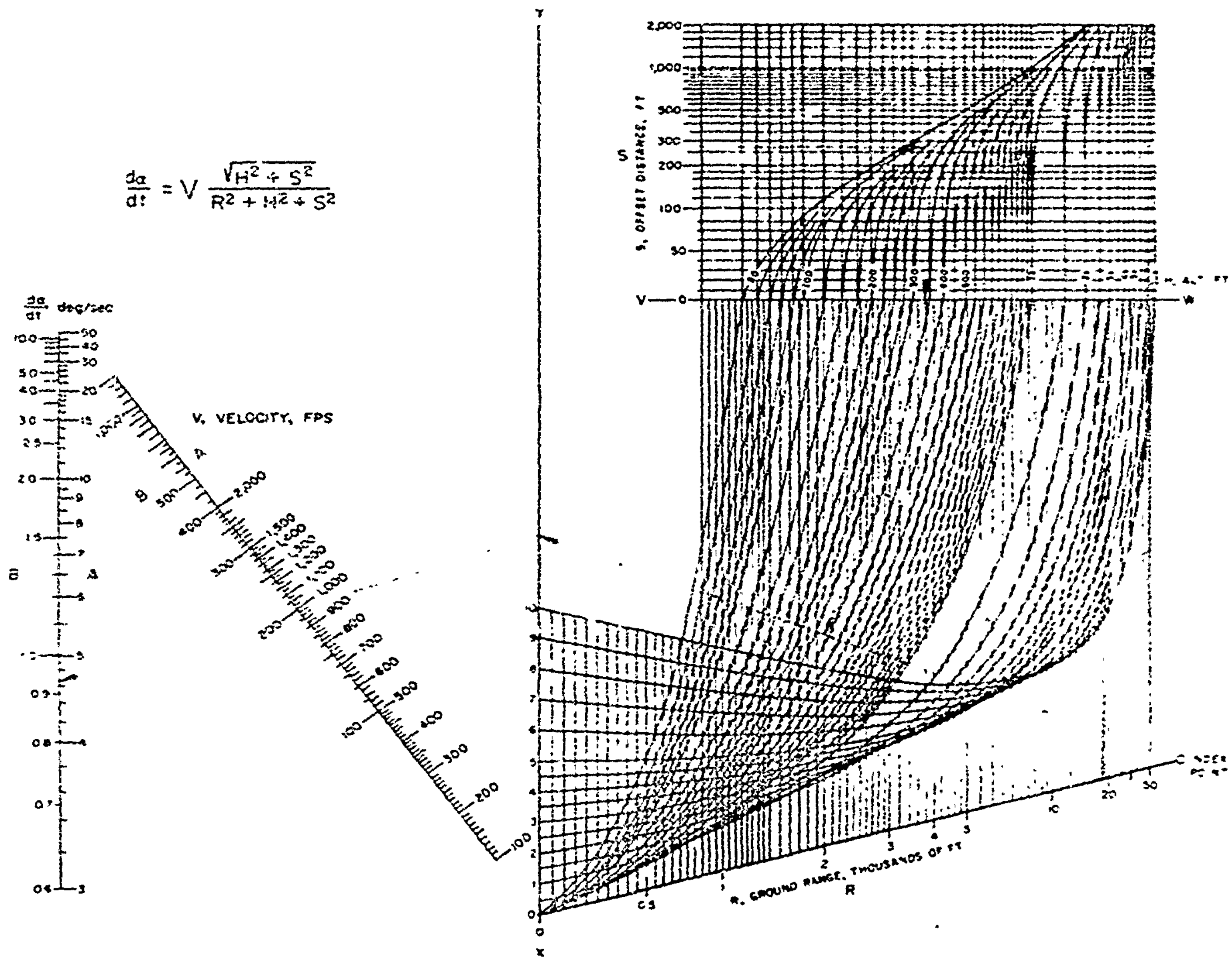
3.2.5 Target Motion

Dyer (1965) reports a field study of air-to-ground target acquisition where vehicular targets are stationary or moving at the time of acquisition. He found no difference in acquisition performance between stationary and moving targets during flight trials at 1000 ft. (304.8 m) altitude and speeds of 550 Kts (1019.2 km/hr) and 700 Kts (1297.1 km/hr), although at a lower altitude (500 ft., 152.4 m) or lower speed (350 Kts, 648.6 km/hr) moving targets were more easily acquired than stationary ones. Direction of vehicle motion relative to the flight path was an important factor.

Erickson (1965) has pointed out three ways in which target movement may enhance the probability of detection. First, a new target may be created by the motion, such as the wake of a ship, or a dust cloud behind a vehicle. This latter effect was responsible for the "apparent" sighting of a Jeep on an unpaved road by an astronaut orbiting 100 miles (160.9 km) above the earth's surface. Calculations by Taylor (1964) show this to be an entirely credible sighting.

Secondly, change in the location of the target due to its motion may be noted. Third, the motion, per se, of the target may attract the observer's attention. However, the angular velocity due to the movement of the target over the ground must be discriminable from the apparent angular velocity of the ground at that point due to the aircraft's motion. If target angular velocity is not discriminable from ground angular velocity, then target movement, per se, cannot provide enhancement of the detection performance.

A feature of this study by Erickson was the creation of a nomograph for computing angular rate. Figure 3-1 is a representation of the nomograph; the following are the instructions for its use.



SOURCE: ERICKSON, 1965

Figure 3-1. Nomograph for Computing Angular Rate in Level Flight

INSTRUCTIONS FOR USE OF ANGULAR RATE NOMOGRAPH

Given:
(1) S offset distance to target

(2) H aircraft altitude

(3) R range ahead to target

(4) V velocity of aircraft

Desired: $\frac{da}{dt}$, the angular rate of a point on the ground at (R, S),

EXAMPLE:
S = 265 feet (80.77 m)

H = 200 feet (60.96 m)

R = 2,000 feet (609.6 m)

V = 1,000 ft/sec (304.8 m/sec)

Procedure:
(1) Find the desired S (265 ft) on the S-scale on the upper left of the nomograph.

(2) Then go across horizontally until the desired H-curve (200 ft) is intersected.

(3) Go straight down from this intersection to the index line V-W.

(4) Follow the curved lines down until the desired vertical range line (2,000 ft) is intersected.

(5) Draw a line from the index point on the lower right, through the intersection point obtained in (4), up to the index line X-Y.

(6) Now draw a line from this intersection point on the index line, through the desired velocity (1,000 ft/sec), across to the angular rate scale on the far left. The answer (4.67 deg/sec) is obtained on this scale.

(7) For convenience, two different scales, A and B, can be used. In the example mentioned, the A velocity scale is used, so the angular rate must be taken off the A da/dt scale. If the B scale had been used (V = 200 ft/sec) the corresponding angular rate would be 0.93 deg/sec, taken off the B scale.

Scales are given as follows for conversion from ft/sec and m/sec to knots and km/hr and from deg/sec to radians/sec.

0 1 2 3 4 5 6 7 8 9 10 DEG/SEC
0 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 RAD/SEC

0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 M/SEC
0 1.9 3.7 5.6 7.4 9.3 11.1 KM/HR

Dugas and Peterson (1971) say that the reason moving targets are more easily detected than non-moving ones is because of the changing contrast of the target with its background. They found that moving targets produce curves of acquisition similar to non-moving targets but with larger time constants. Their data fitted quite well with Bailey's (1970) assumption of an exponential time dependency for target detection probability. They used televised rectangular targets against an aerial scene and a felt background. A subsequent study by the same author Peterson and Dugas (1971), extended the previous results by utilizing targets having variable speed and contrast. Using a homogeneous dot matrix and a solid square target on a TV monitor, they found that the following equation best summarized the effects of contrast and target motion:

$$P = 1 - e^{-\left(\frac{f}{A_s}\right) A_{d_o} C \,(1 + 0.45\, v^2) t}$$

where: f = glimpse rate, assumed to be three per second

A_s = area to be searched in time t

A_{d_o} = normalized detection aperture; an empirical constant that varies with target size and background complexity

C = contrast of target with respect to background

v = target velocity in deg/sec subtended at the observer's eye

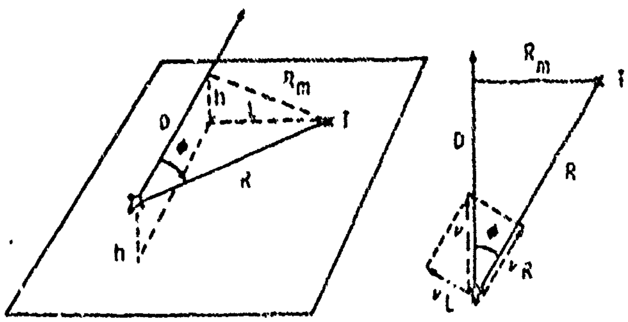
t = search time

This equation contains a linear contrast term and a squared velocity term. Peterson and Dugas maintain that their results indicate that search is more nearly random than systematic, but that with prior knowledge of detection aperture, it should be possible to devise a search strategy that approaches systematic scene search. The use of the term aperture is used in the sense that Bailey uses it, i.e., that the best model of the individual searching a scene is that of a visual aperture which is moved rapidly over the scene and stopped in movement when some suprathreshold point of fixation is detected that might be a possible target. [illegible]ept is a part of glimpse theory which is the basis of many [illegible] Chapter 6).

3.2.6 Scene Apparent Motion

When an observer in an aircraft is looking at the terrain ahead of the aircraft, the terrain appears to be moving toward him. As Greening (1964) has pointed out, ground apparent movement has a degrading effect on dynamic visual detection and recognition. The angular subtense of the target or other objects grows in size; relative position of target to background changes and target lateral features grow at a different rate than do horizontal features.

Unaccelerated flight past a point on the ground produces continuous changes in the line-of-sight, as shown in Figure 3-2. The apparent angular position of a point on the ground changes relatively slowly when the range is large compared to the altitude. As the aircraft approaches the object, its apparent angular motion increases rapidly until it reaches the position of nearest approach, and then recedes, in symmetrical fashion. Figure 3-3 (Greening and Sweeney, 1962) shows curves of angular rates vs time.



$$\dot{\phi} = \frac{\nu_L}{R}$$

But $\frac{\nu_L}{\nu} = \sin\phi = \frac{R_m}{R}$

Hence $\dot{\phi} = \frac{\nu R_m}{R^2} = \frac{\nu\left(h^2 + L^2\right)^{1/2}}{D^2 + R_m^2} = \frac{\nu\left(h^2 + L^2\right)^{1/2}}{D^2 + \left(h^2 + L^2\right)}$

Also, $D = \nu\left(t_0 - t\right)$ Where t_0 is time of nearest approach

Hence $\dot{\phi} = \frac{\nu\left(h^2 + L^2\right)^{1/2}}{\left[\nu\left(t_0 - t\right)\right]^2 + \left(h^2 + L^2\right)}$

Figure 3-2. Apparent Angular Motion of Ground Objects

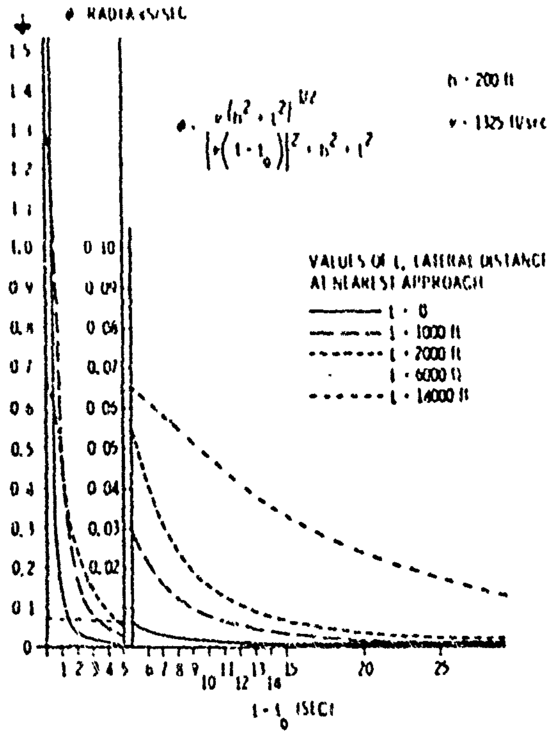


Figure 3-3. Angular Rate as a Function of Time

3.2.6.1 Extended Object Geometry

Greening (1964) provides an excellent discussion of the dynamic properties of the visual field when looking for targets at low altitude." When a collection of points comes under observation, the visual geometry becomes complex. All the characteristics of the static search, detection, and recognition problem exist simultaneously. The quality of the visual scene changes significantly with time. Some of the changes are:

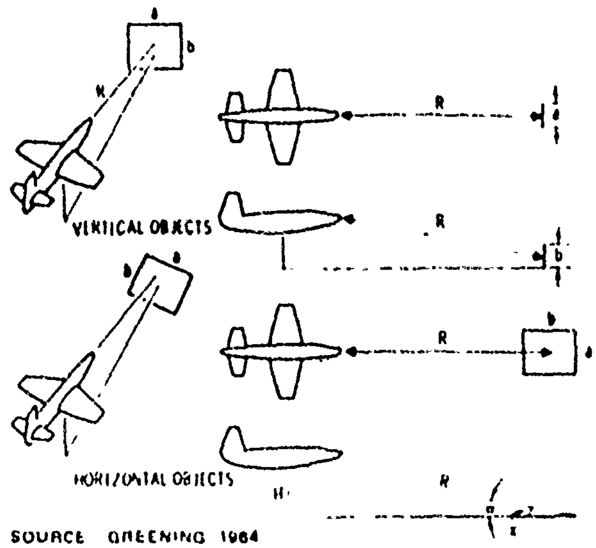
a. Angular Subtense

"The angular subtense of any extended target normal to the line-of-sight is a/R, where "a" is a linear dimension of the target, and "R" is the range to the target. For a rectangular element with dimensions $a \times b$, the apparent area will be ab/R^2 (Figure 3-4). Thus, as the object is approached, its apparent linear dimensions increase as $1/R$, while its apparent area increases as $1/R^2$.

"For a small horizontal surface, the lateral subtense is again approximated by a/R.' The vertical subtense involves the altitude, H. For small angles, the vertical subtense will be:

$$\frac{x}{R} = \frac{H}{R} \cdot \frac{b}{R} = \frac{Hb}{R^2}$$

Thus, a linear feature along the flight path will lengthen apparently as $1/R^2$ while lateral linear features are growing as $1/R$. The apparent proportions of horizontal (or inclined) surfaces will thus be changing with time.



SOURCE GREENING 1964

Figure 3-4. Subtense of Distant Objects

"Following the same reasoning, the apparent solid angle subtended by a small horizontal surface will be approximated by

$$\frac{a}{R} \times \frac{Hb}{R^2} = \frac{AH}{R^3}$$, where A = a x b, the area of the horizontal surface.

"In a target complex made up of a horizontal area with projections on it (e.g., buildings on flat ground), the total apparent angular subtense of the horizontal elements will be increasing faster, $1/R^3$, with decreasing range than the vertical elements, $1/R^2$ (Figure 3-5). Thus, at a distance, a village appears to be almost all buildings, fences, etc., while from closer range (more oblique aspect) it seems to be mostly ground, roads, etc.

"This relationship holds also for objects too small to be individually resolved, such as grass, pebbles, etc. The result is an inevitable change in visual texture and, usually, in apparent brightness and color as well, independent of atmospheric effects or visible details.

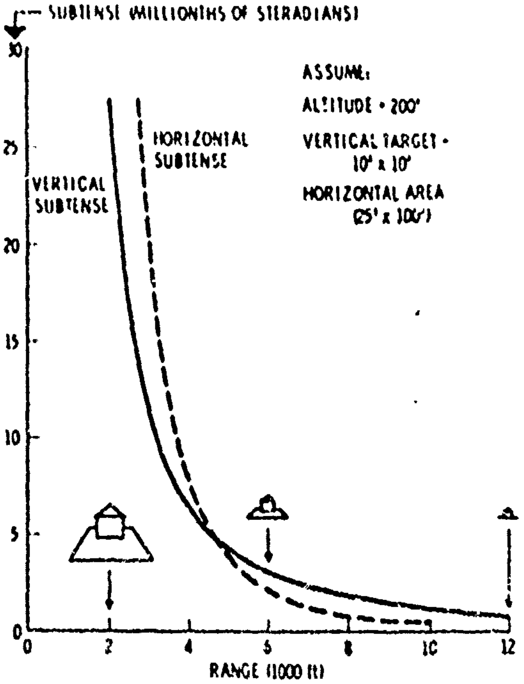


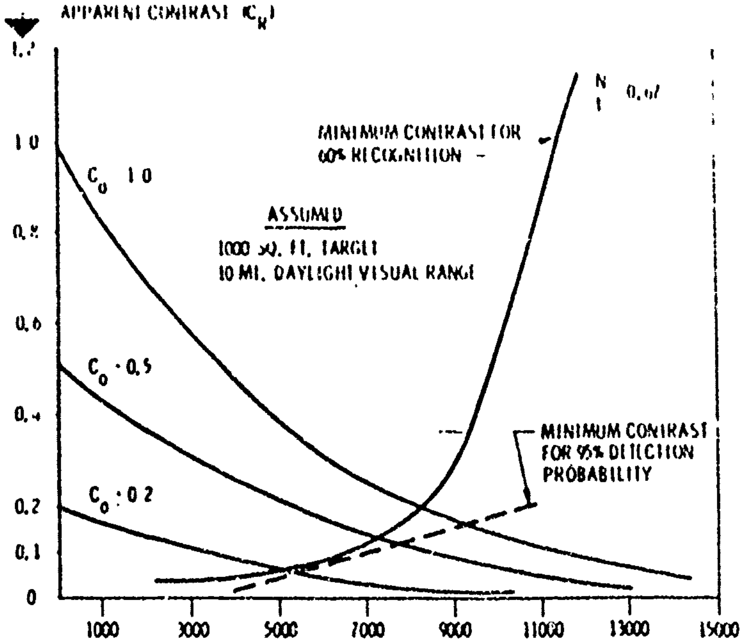
Figure 3-5. Apparent Size of Horizontal and Vertical Surfaces

b. <u>Apparent Relative Position</u>

"The apparent relationships among separated points in the visual field also undergo continuous significant changes when viewed from a low-altitude vehicle. For objects viewed as a pattern, this means that the aspect of the pattern varies with time.

"For more widely separated objects, some or all of which have significant vertical extent, observer motion at low altitude produces the effect of intermittent, partial or total masking of one object by another. Such masking effects seem certain to have an important effect upon airborne recognition performance, but data and descriptive metrics are lacking.

"All the geometric effects described above interact with the static visual variables such as contrast (brightness and color), shape, atmospheric attenuation, clutter in the visual field, etc. Greening (1962) has made one brief analytical attempt to combine these variables in a form usable for quasi-dynamic prediction. Using static data presented by Middleton (1952) and Boynton et al (1958), we have plotted apparent contrast as a function of range, meteorological conditions, and target size (Figure 3-6)." (Pages 4-9).



SOURCE GREENING, 1964

Figure 3-6. Recognition Range and Apparent Contrast

3.2.7 Target/Background Brightness Contrast

Target/background brightness contrast is a way of quantifying the difference in brightness between the target and its immediate background. It is usually defined as:

$$\text{Contrast } (\%) = \frac{B_t - B_b}{B_b} \times 100$$

where B_t is the brightness of the target and B_b the brightness of the background. Contrast thus defined may be positive or negative according to whether the target is brighter than its background or vice versa.

In most target acquisition studies, inherent contrast, that is, the target/background contrast measured at the real-world target, is of less significance than apparent contrast. Apparent contrast is the contrast between target and background measured at the observer's eye. This depends on the inherent contrast, the slant range of the target, the characteristics of the intervening atmosphere and, if an intermediate viewing system such as television is used, its transfer characteristics. In general, the greater the slant range of the target, the greater the loss of contrast due to atmospheric attenuation. The extent of the loss depends on the density of dust and water particles in the atmosphere. Problems of vision through the atmosphere are extensively discussed by

Middleton (1952) and data presented by Duntley (1948) are often used to calculate the effects of the loss of contrast on slant range and atmospheric attenuation.

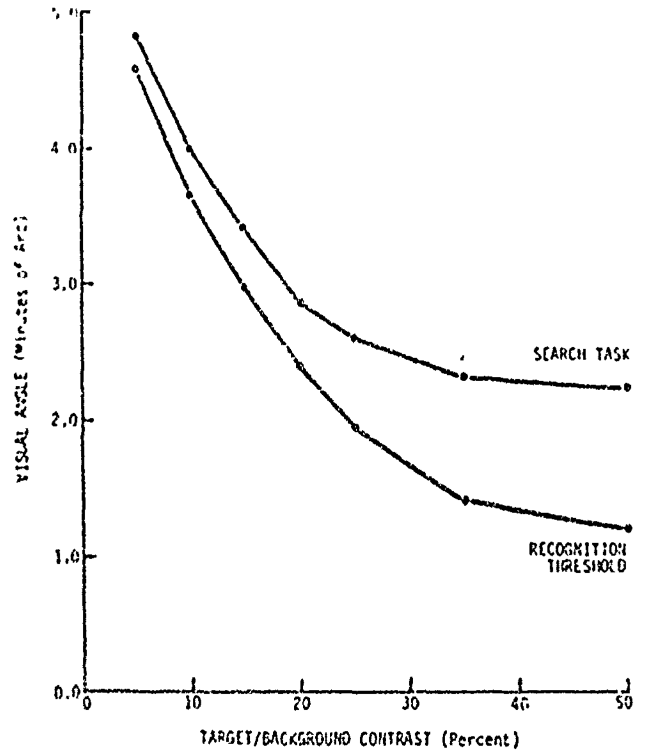
The effects of target/background contrast have been extensively studied analytically and in laboratory experiments (see, for instance, Blackwell, 1946; Lamar et al, 1947; Taylor, 1960(a) and (b); Vos, Lazet and Bouman, 1956). These studies are primarily concerned with contrast thresholds for simple targets of different sizes against uniform backgrounds.

Laboratory conditions are vastly different from those of air-to-ground target acquisition tasks. Basic contrast threshold data have been incorporated into predictive models of target acquisition performance. There have been relatively few field tests or simulator studies of air-to-ground target acquisition in which apparent target/background contrast has been systematically varied. Thackham, Wade and Clay (1966) report a field trial in which target vehicles were located under conditions of high, medium or low contrast, but no contrast measurements are reported. The results showed that the high contrast condition gave significantly longer identification ranges for static targets than the low contrast condition.

A simulator experiment carried out by Ozkaptan et al (1968) studied target/background contrasts ranging between 5% and 35%. The extent to which contrast affected target detection depended on both camera field of view and type of briefing. In a simulation experiment Jones and Bergert (1970) studied the effect of target/background contrast under closely controlled conditions in which the subjects viewed the terrain model directly. The contrast values of the targets against their backgrounds ranged from 5% to 50%. The results indicated that low contrast levels (5 - 15%) resulted in a large decrement in target detection and recognition performance. This is shown in Figure 3-7 where the effect of contrast on the visual angle requirements for recognition is plotted for search and no-search (threshold) conditions. Another study which investigated the effects of contrast using a television system indicated that contrast had a greater effect on performance than under direct-viewing conditions (Bergert and Fowler, 1970).

3.2.8 Clutter

Laboratory experiments have shown that as the number of objects in a complex visual field increases, target recognition performance deteriorates (Boynton and Bush, 1957; Christner, Schutz and Ray, 1959; Williams and Borow, 1963). In air-to-ground target acquisition tasks the terrain is usually cluttered with objects other than the target. Simulations and field studies have shown that the same effects occur: a greater degree of clutter leading to a deterioration in target acquisition performance. A factor also likely to cause performance deterioration is that the more objects in the visual field, the higher the possibility that one or more of these objects will partially or completely mask the target. This effect is heightened by reduction in flight altitude.



SOURCE: JONES AND BERGERT, 1970

Figure 3-7. Visual Angle Requirements for a Recognition Task as a Function of Target/Background Contrast

In a field study of clutter effects Whittenburg et al (1959a) compared the acquisition of targets located in relatively open areas with that of unconcealed targets placed close to natural terrain objects. No difference in performance was found. Similarly, a simulator study carried out by Bergert and Fowler (1970) showed that a background cluttered by non-target objects such as trees or rocks did not affect the subjects' ability to distinguish the targets, as compared with open field backgrounds. This was also found by Van Arsdall (1974).

These results indicate that clutter per se does not always have a deleterious effect on target acquisition. The effect of clutter depends upon whether subjects are trained to search effectively, i.e., to disregard areas where targets are not likely to be. The degree of similarity of the cluttering objects to the target and the conspicuity of the target are also factors in determining the effect of clutter on target acquisition. An easy acquisition task will make the target stand out like the proverbial sore thumb and therefore the subject will not have to fixate as many target-like clutter objects.

A major problem in studying the effects of terrain clutter is that of quantifying the degree of clutter. This has been attempted by Nygaard et al (1964) using various forms of sensor imagery, including aerial photographs. Using a stimulus-complexity analyzer to measure overall background complexity, a curvilinear relationship was found between the analyzer measure of total object count and recognition performance for both photographic and infra-red imagery. An inverse relationship was found between target recognition time and mean object size and object-size variance. These results suggest that it is possible to quantify some aspects of background complexity in relation to the real-world; further research is needed in this area.

Another important factor closely related to clutter is the degree to which objects in the surrounding terrain resemble the target itself. This factor, usually referred to as target confusability, is considered in Section 3.2.12.

3.2.9 Terrain Type

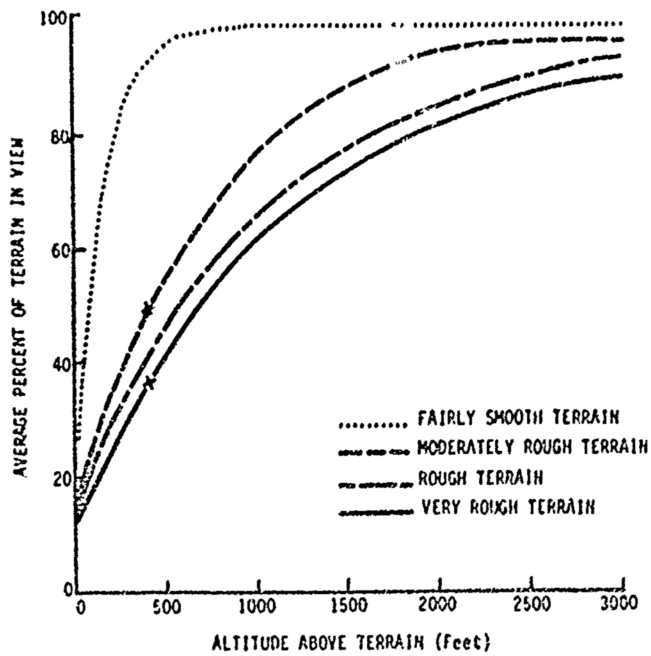
The extent to which acquisition of a target is affected by the nature of the terrain has been studied both analytically and experimentally. Analytical studies (see, for instance, Ballistics Analysis Laboratory, 1959; Erickson, 1961; Greening and Sweeney, 1962; Snyder, 1964) have concentrated on evaluating the probability that a target will be potentially visible, that is, not masked by intervening terrain, at various slant ranges for different flight altitudes and types of terrain.

Terrain type refers to the degree of ruggedness of the terrain, for instance, fairly smooth, moderately rough, or very rough. Terrain has also been categorized in terms such as average gradient and average number of slope changes along sections of fixed length. The presence of mountainous or hilly terrain between the aircraft and the target greatly reduces the probability that there will be a direct line of sight to the target. The target is thus less available for detection, particularly at very low altitudes.

Figure 3-8, which illustrates data from Erickson's study, shows the proportion of terrain in view as a function of altitude for four terrain types, determined from detailed analysis of contour maps. Whether or not a particular target will be in view at a given altitude depends on terrain type and on ground range. For instance, at an altitude of 400 ft. (121.9 m), the probability of the target being in view is approximately 0.50 over moderately rough terrain but this falls to 0.30 over very rough terrain. Data such as these are of value in determining optimum altitudes for particular missions.

Experimental studies of terrain type have been mainly concerned with the effects of different kinds of vegetation and surface covering, which form a background to the target. These effects arise in part from variations in target/background contrast and in the degree of target masking which occur with different terrain types. This result was found by Wyman,

Rawlings and Sturm (1965) in a simulator study of four different terrain types, plain (i.e. grey), rural, desert, and forest. The results showed that masking effects due to the simulated forest background brought about a reduction in recognition probability of approximately 0.20 as compared with the other three backgrounds.



SOURCE: ERICKSON, 1951

Figure 3-8. Proportion of Terrain in View as a Function of Altitude

In another simulation study of background effects, Blackwell, Ohmart and Harcum (1958), also using a terrain model, studied the recognition of vehicular targets against three backgrounds, asphalt, grass and dirt. Slant range of recognition was significantly affected by background type, the dirt background giving the longest ranges and the asphalt background the shortest. The asphalt background also resulted in a substantially lower recognition probability than the other two backgrounds. These results can be attributed to contrast differences.

Field testing has shown that terrain type also affects visual navigation performance. Heap (1965) reported a significantly lower number of successful navigation runs made over terrain in North Germany than were made in Southern England, and a still lower proportion made over South German terrain. A possible reason for this finding is the higher proportion of mountainous and forested terrain in South Germany than in either North Germany or Southern England, with a resulting higher incidence of masking.

3.2.9.1 Terrain Classification

Erickson (1961) empirically studied the effects of gross terrain features upon ground visibility.

He initially classified the terrain by inspection as being fairly smooth, moderately rough, rough, and very rough. A quantitative classification of the terrain was obtained by noting the number of changes in slope direction (from up-to-down or down-to-up) in each 12,000-foot (3657.6 m) section. The average slope of each section was measured in degrees from the horizontal. The equation defining average slope is:

$$\text{Average slope} = \frac{\Sigma|S_n|D_n}{D_t},$$

where S_n is the slope of the terrain, in degrees from the horizontal,

D_n is the horizontal distance, in feet (or meters), through which the terrain has the slope S_n,

D_t is the total length of the section, in the same units as D_n

An example of such a terrain calculation is shown in Figure 3-9.

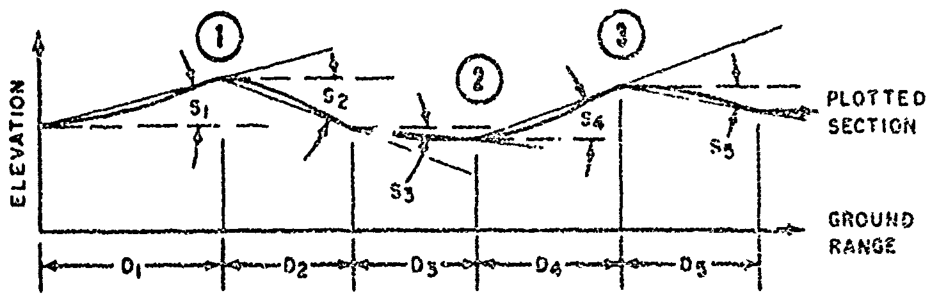


Figure 3-9. Terrain Classification

This figure shows three slope direction changes and an average slope of

$$\frac{|S_1|D_1 + |S_2|D_2 + |S_3|D_3 + |S_4|D_4 + |S_5|D_5}{D_1 + D_2 + D_3 + D_4 + D_5}.$$

Figure 3-10 illustrates Erickson's method of computing degree of obstruction, and Figure 3-11 shows the results of his terrain classification effort.

Ryll (1962) has a good discussion of influence of terrain on target detectability and contains a useful model of terrain masking and the effects of foliage masking. This model is based on a ground roughness survey conducted by the Institute for Cooperative Research (1961).

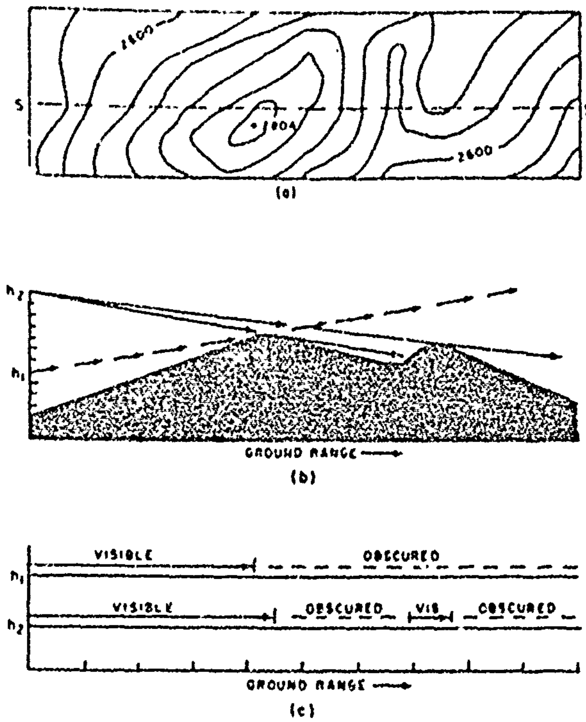


Figure 3-10. Graphic Method of Computing Degree of Obstruction. (a) Plan view, (b) profile of plan S-S, (c) visibility computation sheet.

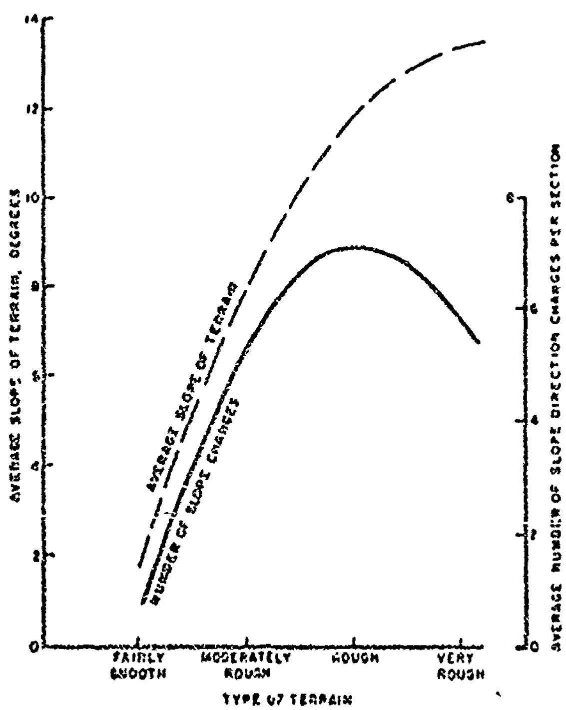


Figure 3-11. Terrain Classification Results

3.2.10 Masking

A target becomes available for detection only when there is a clear, unobstructed line-of-sight between it and the observer. If a target is partially or completely obscured by intervening objects, it is said to be masked. As an aircraft approaches an obscured target a point will come at which the target ceases to be completely masked and, after further travel, finally becomes completely exposed.

The range at which unmasking occurs is critical as it combines with aircraft speed, to determine the length of time available for target acquisition. The apparent size of the target must be large enough, at the time of unmasking, for detection to take place.

The extent to which an intervening object will mask a target depends on the relative sizes and positions of object and target, and the altitude at which the aircraft is flying. The lower the altitude the greater is the likelihood that masking will occur. The main cause of masking is obstruction by hilly terrain, but buildings and vegetation in the vicinity of the target can also give rise to masking effects.

From a knowledge of the geometry of a particular situation, i.e. size and position of object and target, and aircraft altitude, the degree of masking which will occur at any particular range can be calculated; the range at which complete unmasking occurs can also be predicted.

Rusis and Rawlings (1966) performed a low-level high speed air-to-ground photographic simulation investigating the effects of masking and level of reconnaissance/intelligence information. They not unexpectedly found that the higher the level of masking due to terrain or atmospheric conditions, the worse was the level of recognition performance of their subjects. They also found that the heavier masking (shorter range to unmask point of target) resulted in a shorter acquisition time, i.e., the mean time between target availability and correct recognition (3.95 seconds for heavy masking, 6.23 seconds for medium; and 8.81 seconds for light). They explain this result by a possible tendency of their subjects to search for targets in areas which were closer to the aircraft, or because targets that are heavily masked become exposed at shorter ranges than do lightly masked targets. A third possible explanation is that due to the close range of the targets at unmask point there was not as much time available for recognition as for the lighter level of masking. This constrained the data to the shorter recognition times that were found.

Masking effects have not been systematically studied in field tests or by simulation techniques although Whittenburg et al (1960a) report that target detection and recognition scores dropped substantially when targets were deployed so as to utilize natural concealment. However, exposure time, which depends partially on masking, has been studied experimentally (cf Chapter 5) and has been shown to be a driving function of search success probability.

3.2.11 Vegetation

The type of vegetation in the vicinity of the target affects both the background of the target and the degree of masking likely to occur; these can affect target acquisition performance. Brake (1955) in a field study of air-to-ground target acquisition found that targets in the open were detected approximately 1.8 times as often as those located in wooded areas.

The extent to which targets are masked by surrounding vegetation depends to some extent on the thickness of foliage, which itself depends on the time of the year. Studies of masking effects (Ballistics Analysis Laboratory, 1959) have shown that the probability that a target is exposed at any particular range depends on whether or not foliage is present. For instance, at a range of 3000 ft. (914.4 m) and an altitude of 324 ft. (98.8 m) the probability of a 7 ft. (2.1 m) target being exposed was approximately 90% under no-foliage conditions, but this was reduced to about 30% if foliage was present. At lower altitudes, the effect was even more marked.

3.2.12 Target Conspicuity, Embeddedness, Ambiguity, or Confusability

Target conspicuity refers to the similarity between a target object and the non-target objects in its vicinity, or to that between several target objects. Laboratory studies have shown that the greater the similarity of targets and non-targets, in terms of size, shape and contrast, the greater the search time required for recognition of the target (Bloomfield, 1970; Smith, 1961). Similar effects occur in air-to-ground target acquisition, particularly in the case of small tactical targets, but this has been relatively little investigated.

Hicks and Moler (1966) studied the extent to which confusion occurred in the identification of five different tactical targets in a field situation. They found a wide variation in the percentage of times a target was misidentified. The greatest confusion occurred between the three largest targets which were also the targets that were most likely to be detected. Size and shape similarities were largely the cause of these results.

An experiment of a rather different type, also relevant to the problem of confusability, was carried out by Whittenburg, Schreiber and Richards (1959b). They conducted a series of trials to determine the extent to which real tactical targets could be distinguished from dummy replicas of actual equipment under high-speed, low-level flight conditions. The results showed that dummies could be discriminated from the real targets much more readily for large targets, such as 2 1/2 ton vehicle, than for small targets such as a 1/4 ton vehicle. It is difficult to draw any conclusions from these results without knowing the extent to which the dummies resembled the real targets. Apparently, color, structure, texture, and signs of operational use and weathering helped the subjects to distinguish the real from the dummy targets.

3.2.13 Background Scaling and Interaction

Zaitzeff (1971) attempted to develop a target-in-background metric to be used in the prediction of dynamic visual aircrew target acquisition performance. He used factor analysis and ridge regression to develop a predictor equation of target acquisition. Seven basic parameters were found which accounted for most of the variability in the air-to-ground cumulative target acquisition probability. These predictors were: 1. target length, 2. target width, 3. detail contrast, 4. target contrast, 5. element count, 6. ambiguity, and 7. heterogeneity. These 7 accounted for 79% of the variance in target acquisition probability. This amount of predictive power was obtained when he tested 16 subjects in static target acquisition using 10 scenes of the approach to the target filmed during the JTF-2 program (Wyman, Gilmour, Snyder, Jahns, and McGrath, 1968). The first five parameters are physical and/or photometric measures while the last two are psychophysical. These two psychophysical parameters were scene ambiguity, determined by asking the subjects to determine the average number of target area possibilities in each scene, and scene heterogeneity (judged scene complexity). This study attempted to characterize scene clutter in meaningful predictive ways. The effort should be continued and expanded since it has great possibilities for increasing the accuracy of our ability to predict target acquisition probability and acquisition ranges.

Mendez, Freitag and Hallenback (1972) in analyzing infra-red imagery, found that Fourier transforms of microdensitometric traces across the target-scene interface were a good indicator of scene complexity as judged subjectively. They recommend this method for characterizing background clutter. Unfortunately they did not correlate these relative photometric energy traces with an objective measure of the target acquisition probability of the photographic imager.

3.2.14 Color and Color Contrast

One of the factors that determines whether a target can be detected is that of differences in the color of the target and of the color contrast of the target to its background. Middleton (1936) studied the applicability of the C.I.E. metric to that of colored point sources. Koschmieder (1924) thought that there should be a special theory for the visual range of colored objects by reason of the two contrasts involved, brightness and chromaticity. Brown and MacAdam (1949) measured the visual sensitivities of human vision to combined chromaticity and luminance differences. However, the target acquisition task is such that the targets are relatively small, usually less than half a degree. Middleton (1952) is certain that the threshold of chromaticity difference increases greatly below a subtense of about half a degree. He also shows that an object of any color appears nearly achromatic by the addition of air-light by the time its color contrast with the horizon sky has fallen to such a low value that it will disappear. Even in those cases where the color appears to be just outside the MacAdam ellipse (just noticeably different from source C used by MacAdam - 1942, 1943), color contrast does not have much effect on the visual range of air-to-ground target detection or recognition.

This has been verified for television target acquisition by Fowler and Jones (1972) who found no significant differences in acquisition (detection or recognition) when the same dynamic simulated (terrain table) missions were displayed by color or black and white TV.

In the related problem of air-sea rescue, color contrast does help in the location of rafts and flotation devices. Against a water or water-simulated background, early work indicated that fire-orange was more highly detectable than other hues. Some of the later work indicates that colors in the red band (Munsell colors 10RP to 10R) were more detectable than other hues of the same value and chroma (Farnsworth, Malone and Sexton, 1952). In a series of studies investigating the relative efficiency of different colors for markers and signals, Hilgendorf (1971) found, "... There is little doubt that colors in the red and near-red portions of the electromagnetic spectrum present the best universal signalling characteristics."

A recent study, reported in Van Arsdall (1974) did find statistically different target acquisition performance as a function of target color contrast with a green terrain background on a terrain model when brightness contrast was equated for the three tank target colors (brown, green, and gray). The scale of the terrain table (1000:1) necessitated short viewing distances, and no atmospheric degradation was used to make the simulation approach the real world color contrast attenuation by the atmosphere.

Kraft and Anderson (1973) found no statistically significant difference between achromatic and chromatic imagery when displayed either stereoscopically or nonstereoscopically. They did find that the prediction of target acquisition performance on achromatic imagery was less certain than that obtained on chromatic imagery. This finding helps to confirm the opinion of Middleton that color is not an important variable in target acquisition, especially since the Kraft and Anderson results were obtained by the near real-time dynamic presentation of 1:3000 scale strip imagery moving at 3 degrees per second.

3.2.15 Camouflage and Texture

An intuitive (or naive) view of air-to-ground target acquisition might indicate that the texture of the target would provide a cue to its location. Although no good definition of texture exists in the literature, it has been defined as surface coatings of mud, dirt, etc. However, the three-dimensionality of texture when observed at close range translates into contrast differences at the long ranges usually desired for target acquisition. Freitag (1974) says that texture at least in a simulation terrain table study is not a good variable to test because of its confounded nature with contrast and detail outline and because it is less important than clutter, illumination, atmospheric effects, etc.

A recent classified symposium (Laurence, 1973) on passive counter-surveillance contains several articles on the use of camouflage as a counter-surveillance technique. Of particular interest is the paper given by Bucklin (Chapter 27) on the history and status of small items camouflage.

Camouflage has been studied extensively in ground detection of personnel-sized targets to determine detection range as a function of camouflage variables. Payne (1972), Snyder and Rowland (1968), Greyson and Payne (1971), and Guttman and Webster (1972) discuss several techniques and methods of determining detectability range of camouflaged targets. Little work has been done on camouflage of large targets in air-to-ground detection, primarily because of the wide use of auxiliary sensing devices such as radar, FLIRS, etc., which are not affected by camouflage, at least in the visual spectrum.

3.2.16 Flare Light

MacLeod (1973) has recently reviewed the effectiveness of flare light on visual target acquisition for the Target Acquisition Working Group (TAWG). This report summarizes the flare design characteristics, the flare-observer interface, environmental determinants of flare effectiveness and the strictly human factors aspects. MacLeod comes to the conclusion, after surveying the available literature, that ... "One particular source of weakness in these models (of flare effectiveness) is the injudicious use of data drawn from basic research which may be inapplicable to the complexities of target acquisition in the real-world. Another limitation is the inability to account for unique interactions among variables which require empirical determination." To which can only be added that this criticism could be leveled at all aspects of target acquisition modeling and to the field in general except for field testing where the paucity of field instrumentation adds to the usual field test problems.

Hilgendorf (1969, 1970, 1971a, 1971b, 1972, 1974) has used a small 5 x 18 foot terrain table to evaluate different types of flares, different ignition altitudes, the effects of shielding, and the effect of varying observer altitude.

A big problem with terrain tables is their lack of simulating atmospheric conditions applicable to real target acquisition conditions. Katz, Ase, Raisen, and Hilgendorf (1970), simulated fogs and mists by means of an environmental chamber. Under simulated night conditions with flare illumination, they used aerosol clouds with visual attenuation comparable to real fogs. They studied the effects of fog density, flare intensity and compared unfiltered vision and vision through a yellow haze filter. They found a direct correlation between visual acuity and fog density levels, an interaction between visual acuity, fog concentration, and light levels in the ranges studied. At increased light levels, subjects tended to show slightly less sensitivity to changes in the fog density. No evidence of improved visual performance was observed when the yellow haze filter was used.

Blunt and Schmeling (1968), and Clisham (1969) are excellent sources of data pertaining to the impact of target-background factors in target acquisition utilizing flare illumination. The former have a multi-step planner's guide for selecting an appropriate flare from known physical characteristics of the target being searched for.

Davis (1971) used a 1:160 scale terrain model to determine the amount of ground illumination required for recognition of vehicles and personnel as a function of target illumination angle, range, terrain background and angle of observation. He found that a progressively smaller amount of flare light is needed to recognize the target as the flare moves from a position between the target and the observer at a target illumination angle of 30 degrees, through an overhead position (90 degrees) to a position behind and above the target at 150 degrees.

3.3 Atmospheric Conditions

Atmospheric conditions, particularly visibility, greatly affect target acquisition performance. Analytical studies of target acquisition and mathematical modeling have considered the effects of atmospheric conditions, but field studies often overlook this important determinant of detection/recognition range and probability.

Precipitation has an important effect on acquisition and extreme weather conditions such as fog, heavy rain or snow-fall seriously degrade performance, and sometimes render target acquisition impossible.

3.3.1 Cloud Cover

Cloud cover appears to have an effect on target acquisition performance by virtue of its effect on scene illumination, shadow effects and masking. Whittenburg et al., (1960a) report that cloud cover tended to slightly improve observer efficiency, while Dyer (1964) found that it made little difference. Cloud cover ceiling height was found by Bradley (1974) to have a strong effect on the target acquisition probability under flare illumination due to its effect on the available search time.

3.3.2 Diurnal Variation

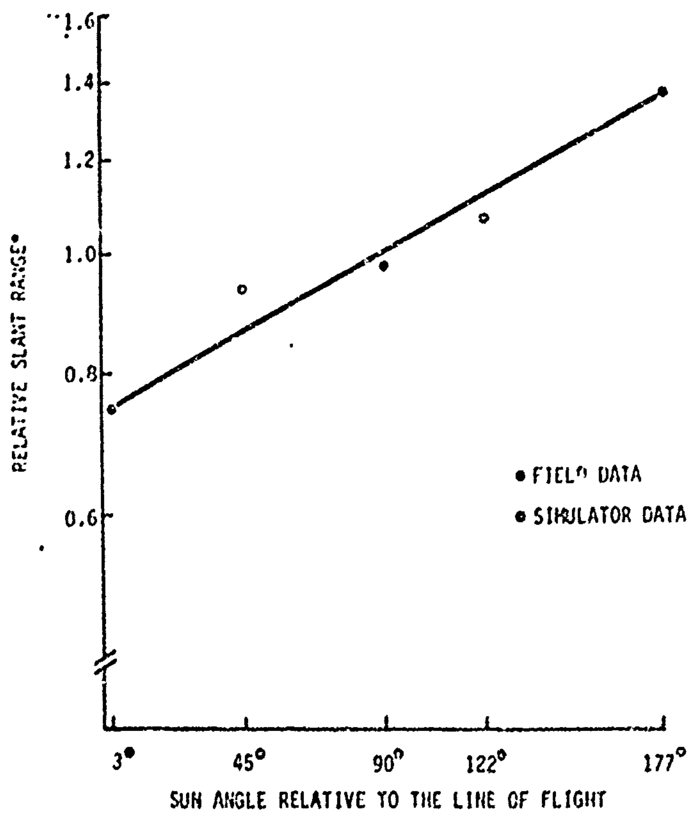
Time of day affects both the general level of illumination on the earth's surface and the position of the sun, in azimuth and elevation, thus altering the nature of the shadows cast. Target acquisition performance could be affected by the time of day at which field trials are carried out, although little systematic work has been done to investigate this variable.

Data that have been analyzed to investigate time-of-day effects have yielded largely negative results. Hicks and Moler (1966) and Snyder et.al., (1966) failed to find any significant effects due to time of day in studies conducted under daylight conditions.

There is evidence that the decrease in illumination occurring shortly after sunset is very important in determining the range at which targets can be detected (Hecht et al., 1944). Although studies have been carried out to evaluate low-light sensor systems, there are no reports of studies in which direct, unaided target acquisition performance has been compared for daylight and twilight conditions. Results quoted by Whittenburg et al., (1960a) indicate that night-time illumination conditions preclude the effective detection and identification of targets.

3.3.3 Sun Angle

Sun angle refers to the direction of the sun in relation to the aircraft's track. The effect of sun angle on target recognition performance has been studied by Blackwell, Ohmart and Harcum (1958) in both field studies and simulation experiments. For the five sun angle values tested an approximately linear relationship was found between slant recognition range, plotted on a log scale, and sun angle, as shown in Figure 3-12. Ranges were greatest when the aircraft track was directly away from the sun's position, and least when the aircraft was flying in the direction of the sun. Forward observation was most seriously affected by glare when the sun was ahead of the aircraft direction of motion.



*RELATIVE SLANT RANGE REFERS TO RANGE EXPRESSED AS A PORTION OF THE OVERALL MEAN RANGE UNDER FIELD OR SIMULATOR CONDITIONS.

SOURCE: BLACKWELL, OHMART AND HARCUM, 1958

Figure 3-12. The Effect of Sun Angle on Slant Recognition Range

Similar results were found by Gordon and Lee (1959) who studied the effect of illuminant azimuth and elevation on the detection and identification of targets in a miniature battlefield. Elevation appeared to have a greater effect on performance than azimuth.

These results are in accordance with the findings of Dyer (1964) that the position of the sun relative to the flight path affected target acquisition ranges during those flight trials conducted when visibility was restricted by haze.

The results of detection have been studied in a number of laboratory experiments. These studies agree that as the level of illumination increases, performance improves until an asymptotic level is reached, beyond which further increases in incident illumination do not have a significant effect on acquisition performance. No relationship was found between the incident light intensity at the time of identification and the accuracy of target identification. But the limited amount of available data did not allow the evaluation of shadow effects.

3.3.4 Illumination Levels

The effect of lighting conditions has been extensively studied both analytically and in field tests. The early work in this area was done by the Camouflage Section of the National Defense Research Committee. The results of this research, which was based on the work of Blackwell (1946) was first reported by Duntley (1948) in a series of nomographic visibility charts that related the liminal (threshold) circular target visibility to angular subtense, illumination level and target/background contrast. Duntley's nomographs provided the minimal distance that a circular target could be seen. In spite of explicit cautions by Duntley, his nomographs have frequently been misused by applying them without taking into account the appropriate field factors in the prediction of target acquisition range. It should also be remembered that the Blackwell data were taken from well-trained subjects with homogeneous test backgrounds, far removed from the operational situation of flight, where terrain backgrounds with non-homogeneous targets of irregular dimensions are the typical conditions of search. Forced choice was used by Blackwell with no search of the visual scene.

To convert from the 0.50 probability of the nomographs to the 0.90 probability in the real world, Duntley recommends halving the inherent contrast of the target before entering the nomographs; this yields a sighting range which he defines as the point where the observer has confidence in his detection of the target. Duntley also developed the basic equation relating target visibility to luminance of the background, meteorological range, and the optical slant range:

$$C_R = (B_o/B_R)\ C_o\ e^{-3.912\ \overline{R}/v} \text{ where}$$

B_o = inherent luminance of the background

B_R = the apparent luminance of the background

$\overline{R}$ = optical slant range

C_o = inherent contrast

V = the meteorological range

This equation describes how the atmosphere acts to attenuate the target/background contrast by scattering and absorption of the light quanta, and shows that it is an exponential function of the optical to meteorological slant range ratio. Meteorological slant range was defined as the distance for which the contrast transmittance of the atmosphere is 2 percent.

Most of the target acquisition modeling, analytic and field data gathering (all having to do with the physical properties of the atmosphere in scattering and absorbing light and/or other types of radiation such as IR, UV and laser wavelengths) have followed the lead of Duntley, notably at the Visibility Laboratory of the Scripps Institute of Oceanography and at the Air Force Cambridge Research Laboratories at Bedford, Mass. Following Duntley's lead, Penndorf, Goldberg, and Lufkin (1952) surveyed the slant visibility problem suitable for direct field use. They extended the usefulness of Duntley's work to airborne (hence slant) visibility under a standard clear atmosphere, a thin fog layer on the ground, two different kinds of visual ranges above the fog layer, and finally a thin dust layer imbedded in the atmosphere between 6,000 and 7,000 feet. They have taken into consideration the position of the sun relative to the visibility horizon.

Under field conditions, the level of illumination depends mainly on the time of day, the degree of cloud cover and the presence or absence of shadow. However, field trials reported by Whittenburg et al., (1959b) indicate that short-term variations in incident illumination do not have a significant effect on acquisition performance. No relationship was found between the incident light intensity at the time of identification and the accuracy of target identification, but the limited amount of available data did not allow the evaluation of shadow effects.

3.3.5 Seasonal Variation

The time of year at which field tests are performed affects a number of parameters relevant to target acquisition performance. These include meteorological conditions, target/background contrast and vegetative masking. The most noticeable seasonal change occurs when the terrain is covered with snow and many of the minor features which normally create a cluttered appearance are no longer visible. In addition, a covering of snow obliterates numerous shades and textures and replaces them by a much higher brightness. For instance, the weighted reflection factor for fresh snow, taken from Erickson (1965), is 0.77 as compared with 0.03 for black earth, 0.09 for paved roads and buildings, and 0.50 for open sea.

The effects of a snow ground cover on navigation and target acquisition are not known. In some cases navigation might be facilitated by the reduction of clutter, which allows some important features, such as railways, to stand out more clearly. The effect of snow on target acquisition performance depends on whether critical details of the target are hidden, and on changes in target/background contrast.

No systematic study of the effects of seasonal variation has been performed, probably because of the inevitably long-term nature of such a study; also, since several variables are confounded, it would be difficult to determine the exact cause of any effects found.

3.4 Visibility

3.4.1 Definition of Visibility

Visibility is the distance of an object from the observer at which the contrast between the object and its surroundings equals the threshold of contrast of the eye, i.e., the object is just at the limit of visibility. This distance is called the "visual range" and is usually denoted by V (in miles) or V_n (in nautical miles).

Meteorological range is defined as the range at which the contrast of a large black object seen against the horizon falls to 0.05, where 0.05 is the value given to the threshold contrast. According to Middleton, threshold contrast values can range from 0.005 to 0.100, but internationally, meteorological range is now defined in terms of the 0.05 value (World Meteorological Organization, 1958) although a value of 0.02 is still sometimes used. Since the attenuation characteristics of the atmosphere vary with altitude, meteorological range which is a slant range measurement, also varies with altitude, increasing as altitude increases.

Since an object cannot become available for detection until it is at a range equal to or less than the visual range, target visibility has some effect on target acquisition performance. Field study results, however, indicate that if visibility is above a minimum of about 3 miles (4.8 km), it has little effect on target acquisition. For instance, Heap (1965) reports that target detection probabilities showed no significant differences in visibility conditions of 4 to 10 miles (6.4 to 16.1 km) as compared with visibility conditions greater than 10 miles (16.1 km). Similar results are reported by Whittenburg et al., (1960a).

On the other hand, Dyer (1964) found that poor visibility caused by haze had a marked effect on the pilot's ability to navigate and detect targets. In hazy conditions, the angle of the sun relative to the flight path was particularly critical. This latter effect is in accordance with analytical studies by Goldberg, Lufkin and Penndorf (1952) which show that visibility in the direction of the sun is always reduced, as compared with that in the half circle opposite the sun which remains approximately constant.

The effect of haze on search time has been studied under static simulation conditions by Townsend, Fry and Enoch (1958). They found that the effect of haze, when simulated by contrast degradation of aerial imagery, was to increase the search time required to locate critical details and lengthen the duration of fixations.

Middleton (1952) outlines four factors which influence how far one can see through the atmosphere: (1) the optical properties of the atmosphere; (2) the amount of distribution of light; (3) the characteristics of the objects being viewed, and (4) the properties of the eye, alone or aided by instruments. Any definition of visibility must be related to these factors. In practice, the term visibility has a number of meanings.

3.4.2 Attenuation of Light in the Atmosphere

Light traversing the atmosphere suffers losses due to absorption and to scattering. This effect is called "attenuation." If the intensity of a parallel beam decreases by a factor $e^{-\beta \ell}$ over a path length of ℓ, β is called the "local attenuation coefficient." In the case of visibility of dark objects against the sky, the light source is provided by the entire air path itself. In the case of slant visibility the light source is provided by the reflected sun and sky light of the object, plus the air light produced between object and observer.

3.4.3 The Attenuation Coefficient

The attenuation coefficient β is composed of two factors, namely β_M, the air molecular scattering coefficient, and β_P the large particle scattering coefficient. Values of β are given in Table 3-I for specific visual ranges. For pure air at sea level, which contains no water vapor or dust, $\beta = 0.0126\ km^{-1}$ $(0.0234\ nmi^{-1})$. β_M decreases with altitude in the same way as the pressure decreases with altitude. Since the atmosphere contains large particles like nuclei and water droplets, a higher value of β_M must be used. Experiments have shown that a standard ordinary clear atmosphere can be assumed (Hulburt's Atmosphere) for estimation purposes. It is based on measurements up to 38,000 feet. Attenuation coefficients at various visual ranges are given in Table 3-II, which assumes that pure air (Rayleigh air) does not exist below 50,000 feet. In this table, the values of β are reduced to sea level pressure. β_P, the large particle scattering coefficient (Mie scattering) is mostly due to the presence of water vapor, carbon dioxide, and ozone. Figure 3-13 shows the relative contributions of these coefficient constituents, in a model clear standard atmosphere. Figure 3-14 shows how the atmospheric attenuation coefficient varies with visibility range.

3.4.4 Slant Visibility

Slant visibility is the ability to distinguish details in terrain from an airplane. Visual detection range can be predicted on the basis of contrast attenuation with range and atmospheric conditions. The main determinant of visual detection range is the object contrast; the larger this

TABLE 3-I

Visual Range V and Attenuation Coefficient β

V		β
nmi	km	mi^{-1}
1/16	.10	62.59
1/8	.21	31.30
1/4	.40	15.65
1/2	.80	7.824
1	1.6	3.912
1 1/2	2.4	2.608
2	3.2	1.956
3	4.8	1.304
5	8.0	0.7824
10	16.1	0.3912
20	32.2	0.1956
30	48.3	0.1304
50	80.5	0.7824
100	160.9	0.3912

Source: Penndorf, Goldberg and Lufkin (1952)

TABLE 3-II

Standard Ordinary Clear Atmosphere

Altitude		Attenuation Coefficient (β)	Horizontal Visibility (V)	
feet	M	mi^{-1}	mi	km
0-3000	0-914.4	0.22	18	28.97
3000-6000	914.4-1828.8	0.17	23	37.01
6000-10,000	1828.8-3048.0	0.09	38	61.15
10,000-50,000	3048.0-15240.0	0.035	111	178.63
50,000-100,000	15240.0-30480.0	0.0234	172	276.80

Source: Penndorf, Goldberg and Lufkin (1952)

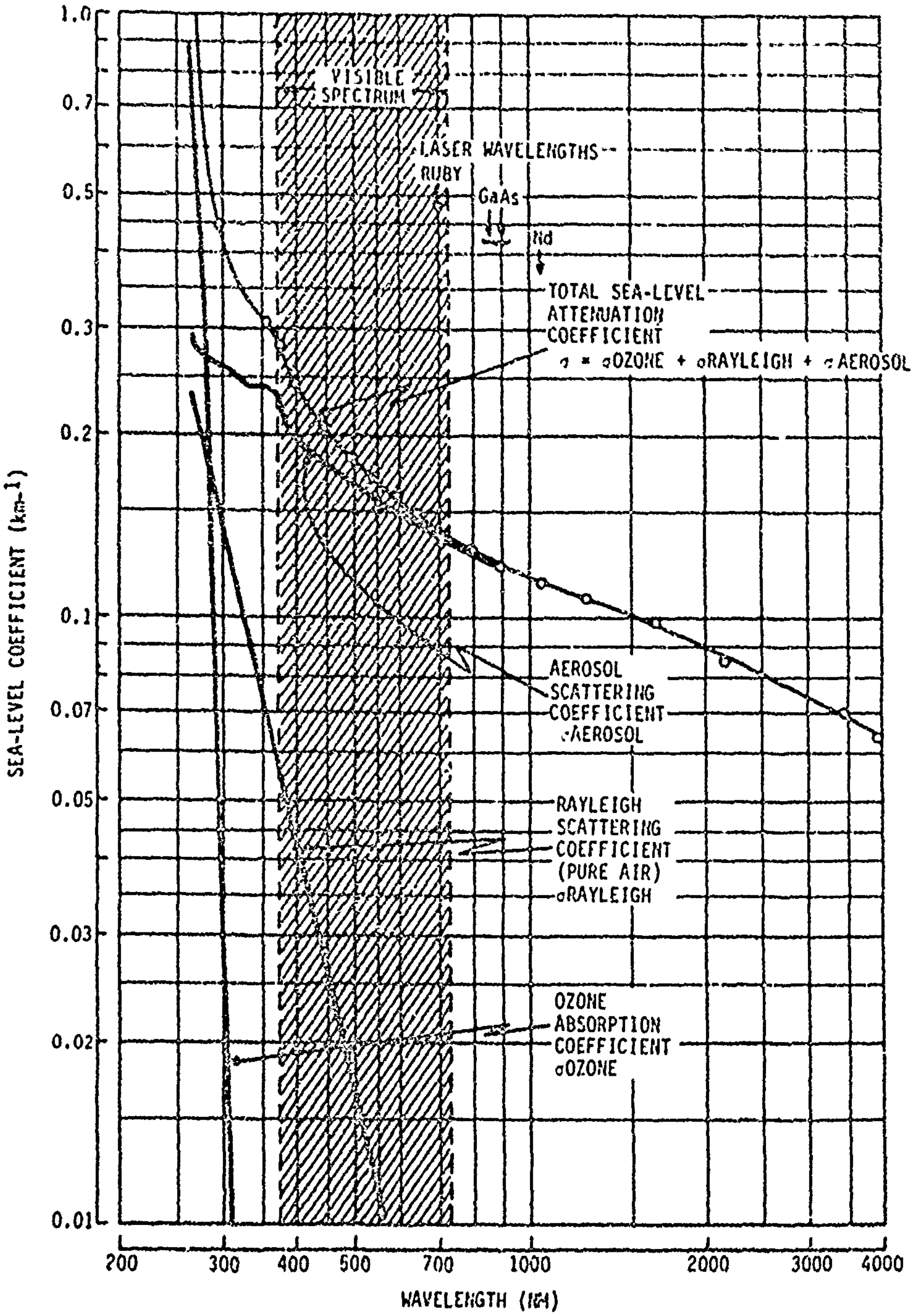


Figure 3-13. Calculated Atmospheric Attenuation Coefficient for Horizontal Transmission at Sea Level in a Mode. Clear Standard Atmosphere. Absorption by H_2O and CO_2, not included, may be appreciable at wavelengths other than those at plotted points.

contrast, the greater the visual range. A slant visual range can be defined only for a predetermined object contrast. There does not exist a general slant visual range which applies to all features in the terrain.

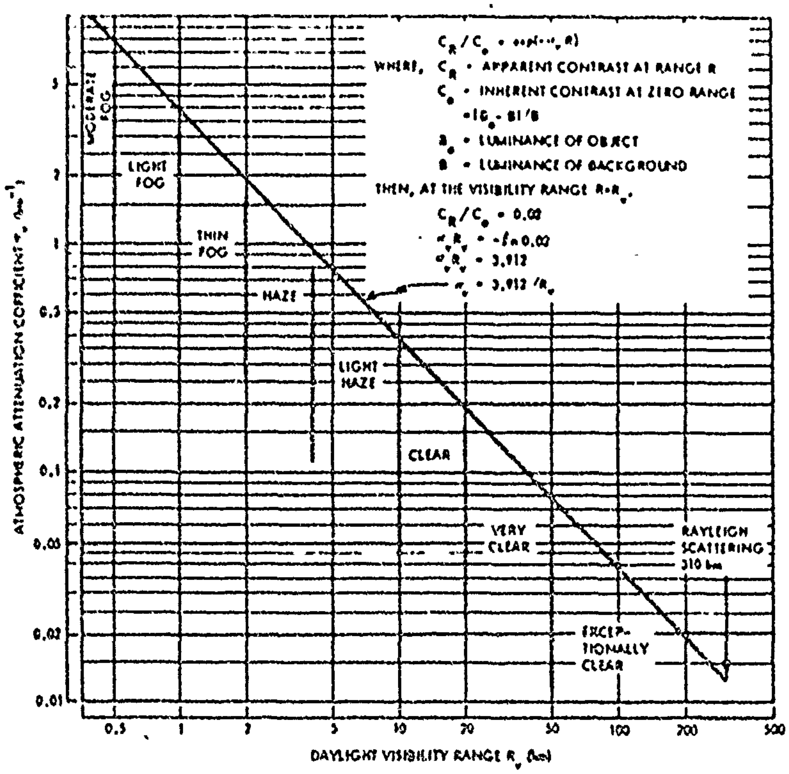


Figure 3-14. Atmospheric Attenuation Coefficient for Visible Light (Extinction Coefficient) as a Function of Daylight Visibility Range (sometimes called "Visibility" or "Meteorological Range")

To determine an object's contrast, the characteristics of the light coming from it and its surroundings can be broken down into component parts.

The light entering the eye is composed of two parts, namely:

1. Light emitted or reflected from the object (reflected sun and sky light) and its immediate background

2. Air light produced in the path between the objects and observer (The air light is the sunlight and skylight scattered by molecules and large particles in the direction of the observer.)

The first of these (a) may be considered the signal while the second one (b) may be thought of as the noise in the contrast discrimination process. Most methods of computing contrast transmission use the target's inherent contrast (at zero range) and attenuate it by atmospheric scattering as a function of range, or as a function of visibility, and light (sun) conditions.

The most important factors which determine the target's detail contrast in terrain backgrounds are:

1. Object contrast (inherent)

2. Altitude of observer

3. Variation of attenuation coefficient with altitude

4. Luminance surrounding the object

5. Nadir distance of the object

6. Zenith distance of sun

7. Azimuth distance of the object from the vertical of the sun.

The first three factors are always important; the last three are very important if the visual horizon in relation to the position of the sun is within the visual field of the observer. The luminance surrounding the object is assumed to be constant.

By international agreement the daylight visual range is the distance at which a large dark object on the horizon is just recognizable. Meteorological range is defined as that horizontal distance R_V for which the contrast transmission of the atmosphere in daylight (C_R/C_O) is two percent, where C_O is the inherent contrast of an object against the horizon sky and C_R is the apparent contrast at range R. To predict target acquisition range, Middleton (1952) shows that apparent contrast C_R reduces exponentially with range R according to $e^{\sigma_V R}$. As shown by the equations on Figure 3-14, the effective value of σ_V, the average attenuation coefficient for the visible spectrum ($380 < \lambda < 720$ nm) depends on the visibility range R_V.

$$\sigma_V = 3.912/R_V$$

where the units of σ_V are determined by the units of R_V. Figure 3-14 is a plot of the above equation, and indicates approximately how R_V is affected by different kinds of weather.

The surface reflectance of the object is also of great importance, i.e., the amount of light directed into the observer's line of sight by the target's surface. Typical reflectance values are given in Table 3-III for different kinds of objects. The data are valid across the visible spectrum, so that targets and background having equal reflectance values should have no contrast. The attenuation coefficient β is also used to determine whether the observed contrast is greater than the contrast threshold using the equation $C_{MIN} = e^{-\beta v}$ where v is the visibility range. The threshold value is generally accepted as that point where contrast is reduced to a 0.02 value. This relationship is derived from Koschmieder's theory.

TABLE 3-III*

Reflectance of Terrain Features in the Visible Spectrum

Feature	Reflectance (%)
Bay	3-4
Bay and river	6-10
Inland waters	5-10
Ocean	3-7
Ocean, deep	3-5
Forest (jungle)	3-6
Forest (open)	4-10
Ground, bare	10-20
Ground, very white	11-15
Ground, some trees	7-10
Fields, dry plowed	20-25
Fields, green	10-15
Fields, green	3-6
Fields, wheat	7-10
Grass, dry	15-25
Snow, white field	70-86
Clouds, dense, opaque	55-78
Clouds, nearly opaque	44-55
Clouds, thin	36-40
Source: Penndorf, Goldberg and Lufkin (1952)	

* This table is used to determine detail contrast as a function of difference in albedo value. The luminance received from two objects adjacent in the field of view is determined by:

$$B_{1\ell} = B_1 e^{-\beta\ell} + B_A(1-e^{-\beta\ell})$$

where: B_1 = luminance of object

B_A = luminance of air light

ℓ = slant range

After computing the luminances of the target and its background (B_2), detail contrast can be computed by using the formula:

$$C_\ell = C_o e^{-\beta\ell} \frac{B_{2o}}{B_{2\ell}}$$

where: C_o = inherent contrast of the target calculated by standard contrast formula, $C_o = \frac{B_{1o} - B_{2o}}{B_{2o}}$

Additional sources of reflectance data may be found in Gordon (Duntley, 1964).

3.4.5 Shimmer or Scintillation

The irregular refraction by the atmosphere of the light rays reflected from an object or in some cases from the terrain background sometimes makes the detection and recognition of targets difficult or sometimes impossible. The index of refraction of the air sometimes varies rapidly and irregularly from place to place, causing shimmer or visual scintillation. This can also be caused by differences in temperature as in the so-called heat waves. Middleton (1952), Bellaire and Ryznor (1961), Bellaire and Elder (1960), Walton (1962), and Erickson (1965) all discuss the importance of this phenomenon on target acquisition slant ranges. This is one factor that has been investigated in the laboratory and can be the possible reason for the large disparity between predicted slant ranges and those found in field studies. It is sometimes called atmospheric boil, optical haze, and/or twinkling. Middleton prefers the term optical haze in daytime and scintillation for nighttime effects but accepts the generic term shimmer. Figure 3-15 shows how the degree of scintillation affects Landolt broken ring resolution.

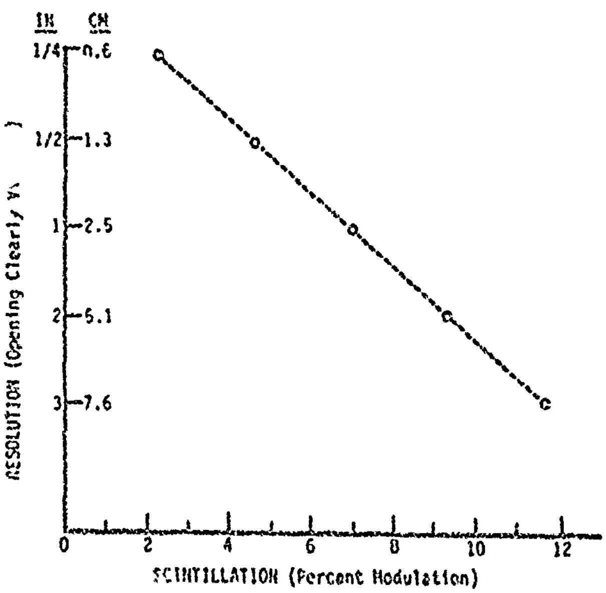


Figure 3-15. Degree of Scintillation versus Resolution Using Landolt Broken-Ring Chart

SOURCE: BELLAIRE AND ELDER, 1960

3.4.6 Glare

If an observer or the subject of a target acquisition study or experiment looks toward a light source, either an illuminant or the sun, excess illumination directed into his eye from the light source often results in the uncomfortable condition of glare or dazzle. Holladay (1926) did the classic research into the ways in which glare affects visibility. He investigated how the required contrast difference between object and background was affected by one or more "dazzle sources" at various points in the FOV. He observed that the obscuring effect of such a source could be

equated to that of an artificially produced "veiling" luminance over the field of view. Holladay found that for the range of luminances he used (0.03 to 3.0 candles/ft^2; 0.0028 - 0.28 candelas/m^2), the amount of veiling luminance varied directly as the luminance produced at the eye by the "dazzle source" and inversely as the square of the angle between the line of vision and the line from the eye to the source up to an angle of 16°. Middleton (1952) calculates the increase in the threshold increment of luminance caused by the disturbing light. He makes the point that increase in effective field luminance caused by the "dazzle source" should be taken into account in determining its effect on the contrast difference limen.

Stiles and Crawford (1937) report the effect of a glaring light source on extrafoveal vision. They verify Holladay's results when the normal component of the illuminance from the disturbing light is used.

Glare has not been treated as a distinct and separate variable in simulation studies or in field tests. Glare is a function of sun angle (azimuth and elevation) and of atmospheric scattering into the line of sight. Sun angle is varied or measured, but glare is never independently calculated or measured, except as a function of target-to-background contrast at the slant range of detection or recognition. A related phenomenon "flash blindness" is the instantaneous effect of high intensity, short duration light flashes into the eye of the observer, which cause short-term inability to detect targets. It has been investigated under laboratory conditions and has been reported under night operational conditions (nearby explosions). However, it has not been investigated under conditions of air-to-ground target acquisition and hence does not come into the purview of this source book.

3.4.7 Contrast Attenuation

Duntley (1948) provides the rationale for determining the apparent contrast of targets from the inherent contrast, the meteorological range and the sky-ground luminance ratio. The mathematical relationship for this (Bittner, 1974) is:

$$C_a = \frac{C_o}{1 - S_{gr}\left[1 - \exp\left(\frac{84{,}900R(1-\exp\ (-0.0000461h))}{r_m h}\right)\right]} \qquad (1)$$

where C_a is the apparent target/background contrast; C_o is the inherent target/background contrast, defined as the absolute value of the brightness difference of the target and background divided by the brightness of the background; h is the differential aircraft altitude (in feet); r_m is the meteorological range (in feet); S_{gr} is the sky-ground luminance ratio; and R is the slant range to the target (in feet). The constants in this equation are appropriate for light in the visible region with terrain at sea level. Other more general formulations of atmospheric transmittance are available in Middleton (1952). Variants of the results that follow can be obtained for other formulations. From the earlier discussion, it is apparent that R and h can be passively estimated; hence, for a fixed C_o,

only two parameters are required to estimate C_a, the apparent contrast of the target: r_m and S_{gr}. These parameters can be estimated under two conditions: (1) when viewing a homogeneous terrain; and (2) when flying over a non-homogeneous terrain.

Homogeneous terrain is characterized by a common variability over its extent. A portion of such terrain can be viewed as a sample of the terrain and its contrast variability. The contrast variability of portions of the terrain at different distances from an observer are estimates of the inherent terrain contrast variance subjected to atmospheric attenuation. Samples of the contrast variance can be obtained at different distances.

Hence, the apparent contrast of a target with inherent contrast C_o, can be estimated by inserting C_o and the obtained estimates of h, r_m, S_{gr}, and R into equation (1). This is valuable when an estimate of C_o is available, a situation that often exists. Inherent contrast values can be calculated for various target/background combinations from tables given in Schaefer et al., (1968) and Condron and Tuolin (1961).

In a moving aircraft, r_m and S_{gr} can be estimated from repeated views of the same portion of the terrain. For example, on a raster line display, the information on a segment of a raster scan line will be represented on different lines as an aircraft moves with respect to the area being presented. Three values of apparent contrast ($\hat{C}_a$), corresponding to three different ranges (r), can be obtained if the same segment of the terrain is represented as three successive raster lines. Of course, the terrain segment will grow in apparent width as it is approached, but the variability of the contrast will be strictly a function of the distance to the segment, given that system response is constant over the spatial frequencies of the terrain segment. Given this case, the three sets of values of $\hat{C}_a$, r, and h can be inserted into equation (1) to form three equations in three unknowns. Solving this system, estimates of r_m and S_{gr} can be obtained even though the terrain is heterogeneous.

Bittner thus has shown that either from a constant view of a homogeneous terrain or from a series of views while flying over a heterogeneous terrain, the terms in equation (1) can be estimated and used to estimate the apparent contrast of a known contrast target located at any point within the field of view.

3.4.8 Atmospheric Modulation Transfer Function (AMTF)

The atmospheric MTF is a useful method of summarizing the effects of the atmosphere on target visibility. Duntley (1948, 1964) is responsible for most of the theory on target visibility measurement and prediction. He states (1964) that if it is assumed that all radiance differences are transmitted by the atmosphere with the same attenuation as that experienced by each image-forming ray, and as a consequence of this assumption, no fine details are obliterated by atmospheric scattering, and if it is assumed that images of distant objects are formed by photons which traverse the intervening media without being scattered, the AMTF summarizes these concepts.

Duntley discusses the work of James L. Harris in deriving the MTF for atmospheric haze. The utility of the MTF concept is that the AMTF can be multiplied with other sources of optical losses to obtain the overall MTF and hence the efficiency of the optical system. A recent book by Cornsweet (1970) discusses the utility of this concept when conceptualizing how visual perception is affected by the optic properties of the lens, optic media, etc.

Brown, Collins, and Hawkins (1968) present a good discussion of the MTF method of optical system analysis and of the utility of atmospheric and visual system MTF concepts. Bittner (1974) also presents an exposition of the MTF method applied to determining the effects of atmospheric MTF on target visibility.

The modulation transfer function (MTF) is a measure of the resolution of a component of an imaging system. Usually applied to optics, camera tubes, video amplifiers, displays, etc., this measure can also be applied to the media of transmission (i.e., the atmosphere). The MTF of an imaging system component is its sine wave spatial frequency amplitude response, a response that varies from unity at sufficiently low spatial frequencies to zero as the spatial frequencies increase (see Figure 3-16 for a typical curve). The AMTF is the MTF for the atmospheric component of an imaging system and is dependent on a multitude of variables including path length (R), wavelength, atmospheric density, ozone concentration, water vapor concentration, etc. These complexities can be ignored when the effective AMTF for air-to-ground observation is obtained by placing targets of different spatial frequencies at different points on the ground and directly measuring the response. The procedure for measuring effective AMTF is similar to the procedure for determining effective contrast attenuation and suggests that the AMTF can be obtained from a display representation in the manner proposed above for determining contrast attenuation. This view will subsequently be confirmed.

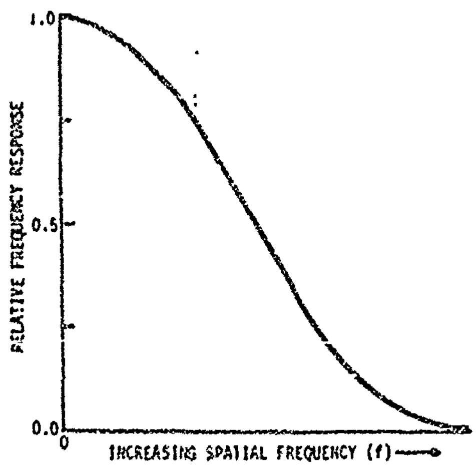


Figure 3-16. A Typical Imaging System Component Modulation Transfer Function

A contrast attenuation function for an object with a spatial frequency f, at the distance of observation R, can be obtained from equation (1) by respectively replacing C_o, C_a, and r_m with $C_o(f)$, $C_a(f)$, and

$$r_m(f) = r_m \left[\exp(-(f/f_c)^n)\right] \tag{2}$$

where $C_o(f)$ and $C_a(f)$ are relative to a frequency f, and both f_c and n are constants. Equation (2) is based on the observation that the decline in the meteorological range for spatial frequency targets can be empirically approximated by a function of this form. Making these substitutions, one obtains

$$\frac{C_a(f_i)}{C_o(f_i)} = \frac{1}{1 - S_{gr}\left[1-\exp\left(\dfrac{84{,}900R_i(1 - \exp\ (-0.000461h_i)}{r_m(\exp - (f_i/f_c)^n)h_i}\right)\right]} \tag{3}$$

where $C_o(f_i)$ is the inherent contrast of a target of frequency f_i, $C_a(f_i)$ is the apparent contrast of the target, R_i is the range of observation, and r_m is the meteorological range for a target of very low ($f_i \to 0$) spatial frequency.

Before considering applications of equation (3), note that the inherent spatial frequency of a target is range-dependent. Indeed, if the spatial frequency of a target at range R_i is f_i, then its spatial frequency at range R_j is approximated by:

$$f_j = \frac{R_j}{R_i}\ f_i \tag{4}$$

when the ratios of frequencies to range are small, because the angular subtense of an object of width d at a distance R approaches d/R radians as d/R approaches zero. This relationship implies that if a target of frequency f_i at range R_i is observed at a range of R_j, then approximately

$$C_o(f_i)_i = C_o(f_j)_j \tag{5}$$

where $C_o(f)_i$ is the inherent contrast of an object observed at range R_i, and f_i and f_j are related by equation (4). This relationship in equation (5) will prove useful in estimating the parameters of equation (3) from samples of terrain viewed at different distances.

Suppose several observations of an object (ground area) at several distances or several observations of a homogeneous terrain were obtained. A spectral analysis of the apparent target images (e.g. segments of a raster line covering an object) would yield the densities of spatial frequencies ($\hat{C}_a(f)$, $f \geq 0$) making up the images or by the decomposition of an image into its spatial frequency components. This can be accomplished for line segments

by methods that are described in Davenport and Root (1958). By methods described earlier, estimates of R_i and h_i can be obtained; hence, equation (3) has only $C_o(f_i)$, r_m, S_{gr}, f_c, and n as unknowns. Assuming that observations are taken at five ranges and recalling equation (5), a system of five equations of the form of equation (3) can be formed. Estimates of r_m, S_{gr}, f_c, and n can be obtained by solving this system. Inserting estimates of these unknowns into equation (3) and letting $T(f)_s = C_a(f)_s/C_o(f)_s$, an AMTF for a frequency f at a distance R_s can be obtained because

$$AMTF(f)_s = \frac{T(f)_s}{T(0)_s} \tag{6}$$

Hence, an empirical expression for the AMTF can be obtained from direct observation of the terrain. This expression can be used to estimate the spectral signal for a target observed at a distance.

The above assumed the observation of ground objects, but did not consider that the observing system has its own MTF. This was intentional and was motivated by the ease with which the problem can be handled when, as is usually the case, the observing system is effectively "linear." Noting that the function for AMTF (equation 6) describes a linear system, and assuming the MTF of the system is also linear, the system MTF is described by

$$MTF_s(f) = (MTF_{E/O}(f))\ (AMTF(f)) \tag{7}$$

where $MTF_{E/O}(f)$ and AMTF(f) are the sensor and atmosphere MTFs, respectively. This expression implies

$$AMTF(f) = \frac{MTF_s(f)}{MTF_{E/O}(f)} \tag{8}$$

which indicates that, with prior knowledge of $MTF_{E/O}$, its effects can be partialed out before any calculation of AMTF. Not adjusting for the effects of $MTF_{E/O}$ would be an acceptable alternative because the calculations of AMTF by the methods described earlier would yield the system MTF - the desired function for practical calculations. Clearly, $MTF_{E/O}$ presents no particular difficulties when calculating either the atmosphere or system modulation transfer functions.

3.4.8.1 Simplified Estimation of Atmospheric Characteristics

In the previous sections, the demonstrations were based on Duntley's results; i.e., equation (1). Often this expression is unnecessarily complicated as, for example, when flying near the earth with the sun at zenith (or not present). In these cases, an adequate expression for contrast attenuation is

$$C_a = C_o \exp(-\sigma R) \tag{9}$$

where σ is positively valued and inversely proportional to meteorological range (r_m); C_a is the apparent contrast; C_o is the inherent contrast; and R is the path length. Using equation (9) would simplify the determination of contrast attenuation by simplifying the form and number of unknowns. This simplification would carry over to the problem of determining AMTF. Following the derivation of equation (3), we substitute $C_a(f)$, $C_o(f)$, and $r_m \exp(-f/f_c)^n$ for C_a, C_o, and r_m in equation (3). This results in an expression of the form

$$\frac{C_a(f)}{C_o(f)} = \exp\left[-\sigma \exp\left(\left((f/f_c)^n R\right)\right)\right] \tag{10}$$

where σ, f_c, and n are unknowns. Equation (10) can be used in the manner of equation (3) to obtain either an estimate of AMTF or the system MTF; i.e., MTF_s. Its advantage over equation (3) is that it has fewer unknowns and a simpler structure.

3.4.9 Sources of Illumination Level and Spectral Characteristic Data

RCA's Electro-optics Handbook (1968) contains invaluable information on the amount and spectral characteristics of natural sources of target and scene illumination. Valley's Handbook of Geophysics and Space Environments (1965) is another source of geophysical data. In the case of infrared radiation, Wolf's Handbook of Military Infrared Technology (1965) should be consulted for data and methodology.

Figures 3-17 and 3-18 together provide a summary of the scenic ambient light levels. Curves to indicate illuminance under cloudy moonlight may be drawn by displacing downward the given moonlight curves by the same amounts as for cloudy sun curves (compared to the unobscured sun).

3.4.9.1 The Sky

On a clear day, about one-fifth of the total illuminance E at the earth's surface is from the sky, that is, from sunlight scattered by the earth's atmosphere. Illuminance is the luminous flux incident in a surface; its unit is the footcandle (fc) and it is equal to the illumination falling on a surface 1 foot from a 1 candlepower source. A meter candle (mc), or lux equals the illumination falling on a surface 1 meter from a 1 candlepower source; it also is called lumen per square meter. Table 3-IV lists some approximate levels of scene illuminance from the day and night sky under various conditions.

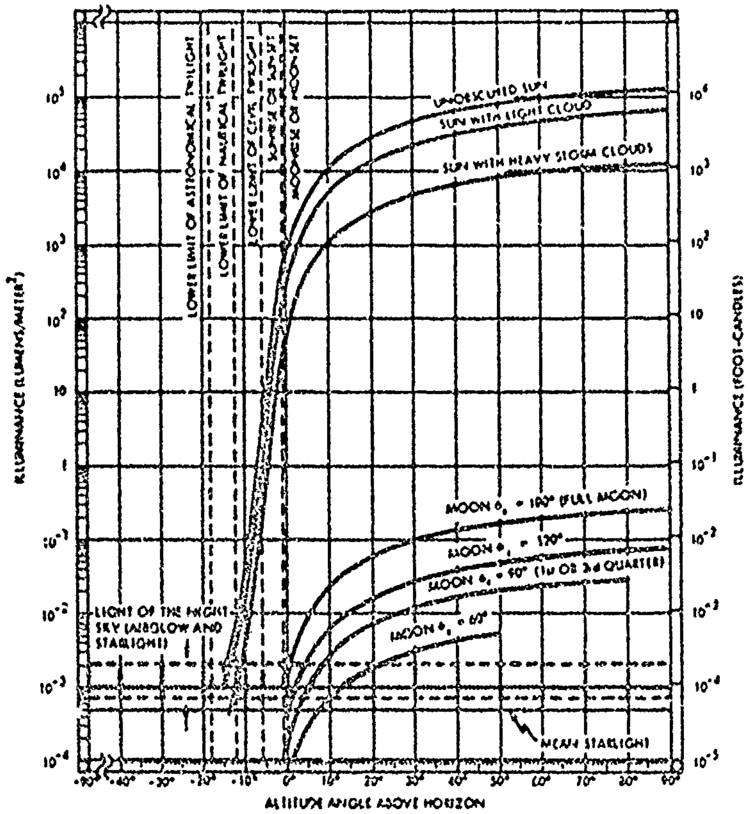


Figure 3-17. Illuminance Levels on the Surface of the Earth Due to the Sun, the Moon, and Sky

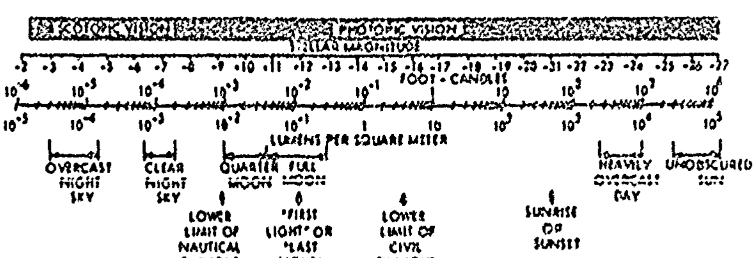


Figure 3-18. Range of Natural Illuminance Levels

TABLE 3-IV

Natural Scene Illuminance

	lm/m^{-2} or meter candles
Direct sunlight	$1-1.3 \times 10^5$
Full daylight*	$1-2 \times 10^4$
Overcast day	10^3
Very dark day	10^2
Twilight	10
Deep twilight	1
Full moon	10^{-1}
Quarter moon	10^{-2}
Starlight	10^{-3}
Overcast starlight	10^{-4}

*Not direct sunlight

Table 3-V gives approximate values of the luminance (B) of the sky near the horizon and under a variety of conditions. Luminance is the brightness of an illuminated surface. Its unit is typically candles per square foot (cd/ft^2) or candles per square meter (cd/m^2). The word candle was officially changed to candela by the U.S. Congress in 1964.

In determining the sky's brightness, the relationship:

$$\frac{\partial E_n}{\partial \Omega} = B$$

is used. This equation means that the incremental change in illuminance at the observer, E_n (light flux per square meter of surface normal to the line-of-sight) per increment of Ω (solid angle of sky) is equal to the sky luminance B.

TABLE 3-V

Approximate Values of the Luminance of the Sky Near the Horizon Under Various Conditions; Source, RCA 1968

	cd/m^2
Clear day*	10^4
Overcast day	10^3
Heavily overcast day	10^2
Sunset, overcast day	10
1/4 hour after sunset, clear	1
1/2 hour after sunset, clear	10^{-1}
Fairly bright moonlight	10^{-2}
Moonless, clear night sky	10^{-3}
Moonless, overcast night sky	10^{-4}

3.4.10 Atmospheric Transmittance

If a source emits radiation with intensity J, the irradiance H at some distance R from the source is calculated according to the inverse square rule to be J/R^2 if the path is through a vacuum. However, if the path is through a gaseous atmosphere, some of the radiation is scattered and some is absorbed so that

$$H = T_a \frac{J}{R^2}$$

where T_a is a factor less than unity that denotes the transmittance of the atmosphere over the designated path.

Atmospheric transmittance T_a is a function of many variables: wavelength, path length, atmospheric gases, pressure, temperature, amounts of rain, fog, snow, dust, aerosols, bacteria, and the sizes of their particles.

3.4.10.1 Entire Atmosphere

Figure 3-19 shows the spectral transmittance (in percent) through the entire atmosphere (from sea-level to outer space) along paths inclined to the zenith by 0, 60, and 70.5 degrees. These inclinations provide path lengths within the atmosphere that traverse air masses of ratio 1, 2, and 3 respectively. These curves indicate the net loss from all scattering and absorption mechanisms in a fairly clear atmosphere. Besides scattering by air molecules (Rayleigh scattering) there is scattering by the larger aerosol particles (Mie scattering). Various spectral regions of absorption are indicated on Figure 3-19. The most important are due to water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3). For most applications the absorption by the other constituents is negligible.

3.4.10.2 Horizontal-Path Transmittance

The transmittance of the atmosphere over a path of length R may be expressed by

$$T_a = C_R/C_0 = e^{-\sigma R}$$

where σ is called the "attenuation coefficient" (sometimes "extinction"). The coefficient is a function of many variables including path length R and wavelength λ. Usually, σ is not independent of path length unless (1) the transmission path is horizontal through atmosphere of uniform composition and (2) the radiation frequency band is extremely narrow as in the case of laser transmissions. Sometimes the attenuation coefficient for each of several atmospheric constituents can be calculated separately and summed to obtain the total effect on transmittance. In the spectral region $200 < \lambda < 400$ nm, Figure 3-13 shows the sea-level attenuation coefficient for a horizontal path in a model clear standard atmosphere (sea-level visibility approximately 23.5 km). It is the sum of the ozone absorption coefficient, the Rayleigh scattering coefficient, and the aerosol scattering coefficient.

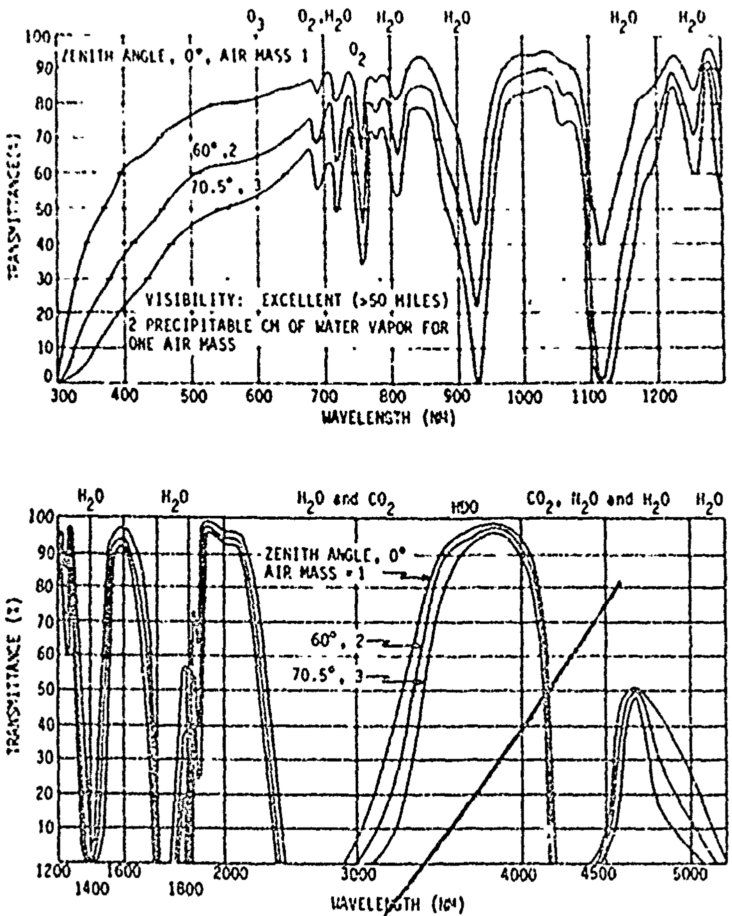


Figure 3-19. Spectral Transmittance of the Earth's Atmosphere for Varying Optical Air Masses. (Adapted from Carpenter and Chapman - 1959)

Other absorbers, water vapor, carbon dioxide, etc., are not included in this model. These absorption effects are highly dependent upon wavelength and absorber concentrations. They may be determined by methods such as the one given in Valley (1965). They are, however, generally negligible for narrow band radiation at the specific wavelengths plotted (though not necessarily negligible at intermediate wavelengths).

Scattering by water droplets (rain, fog, and snow) is treated by Gilbertson (1966).

3.4.10.3 Calculation of Atmospheric Transmittance

The following is a simplified method for calculating the transmittance of the atmosphere over various path lengths at various altitudes of both horizontal paths and slanted paths.

The simplified calculation procedure uses the three Figures 3-20, 3-21, and 3-22. Figure 3-20 gives the attenuation coefficient at sea-level, gives the desired wavelength and shows the conditions of the atmosphere, the latter being identified either by the visibility range or by the general descriptive phrases on the figure. It will be noted that Figure 3-21 follows directly from the "total, sea-level" curve in Figure 3-13 (which applies to the standard clear atmosphere with a visibility of 23.5 km) and an extrapolation to different atmospheric conditions as given in Figure 3-14.

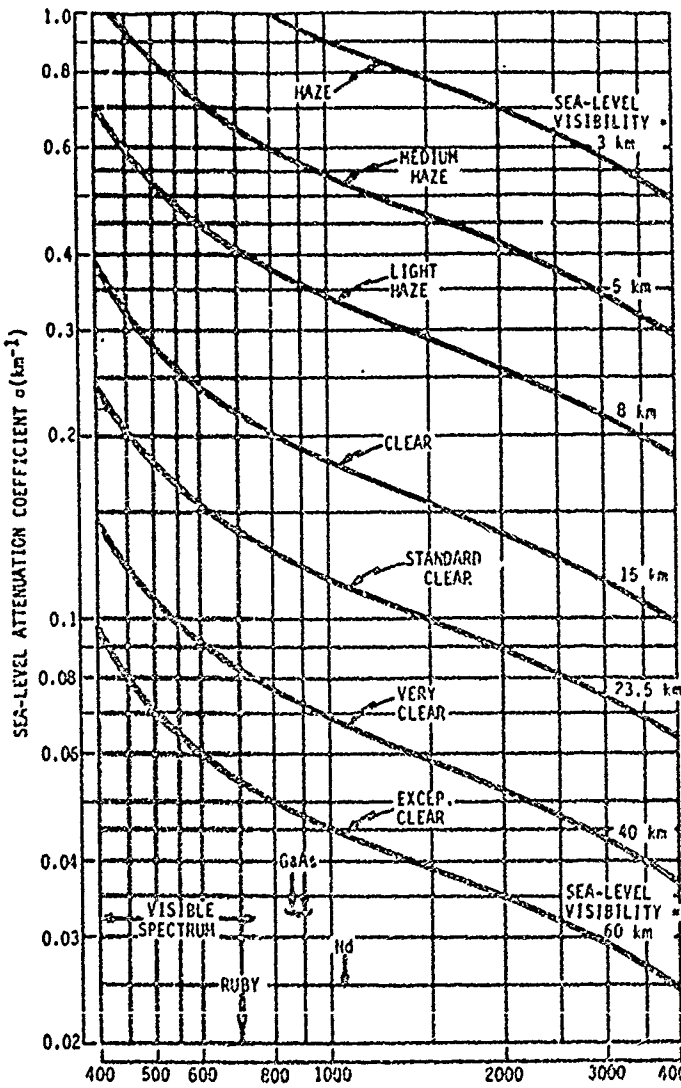


Figure 3-20. Approximate Variation of Attenuation Coefficient with Wavelength at Sea-Level for Various Atmospheric Conditions (Neglects Absorption by Water Vapor and Carbon Dioxide). Source: RCA, 1968

Figure 3-21 provides a correction factor for σ as a function of altitude for either of two cases. The lower curve gives the correction factor for horizontal paths at the specified altitudes and the upper curve gives the correction factor which applies to a slant path from sea-level to the specified altitude. The horizontal path curve is obtained from the standard clear atmosphere model of Table 7-4, in Valley (1965), assuming that non-clear atmospheres have similar profiles. The slant path curve is obtained by integrating an exponential approximation of the standard atmosphere over the appropriate paths, so is presumably less accurate than the horizontal path curve.

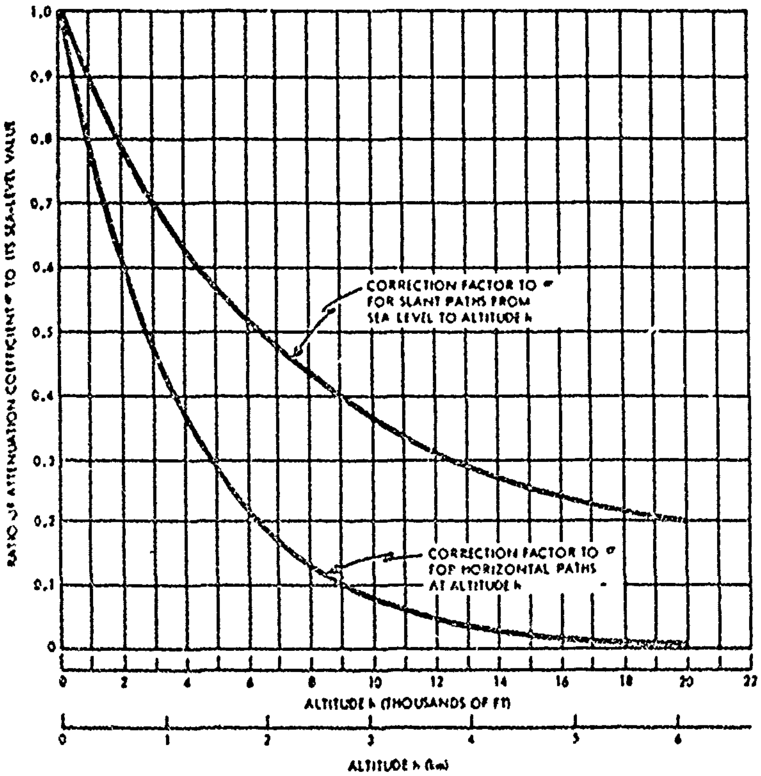


Figure 3-21. Approximate Ratio of Attenuation Coefficient to Sea-Level Value for Slant Paths and Horizontal Paths (Neglects Absorption by Water Vapor and Carbon Dioxide)

Figure 3-22 provides a simple way to use the preceding data in obtaining the atmospheric transmittance T_a, where the abscissa is the product of the path length, the sea-level value of σ (from Figure 3-20), and the altitude correction factor (from Figure 3-21).

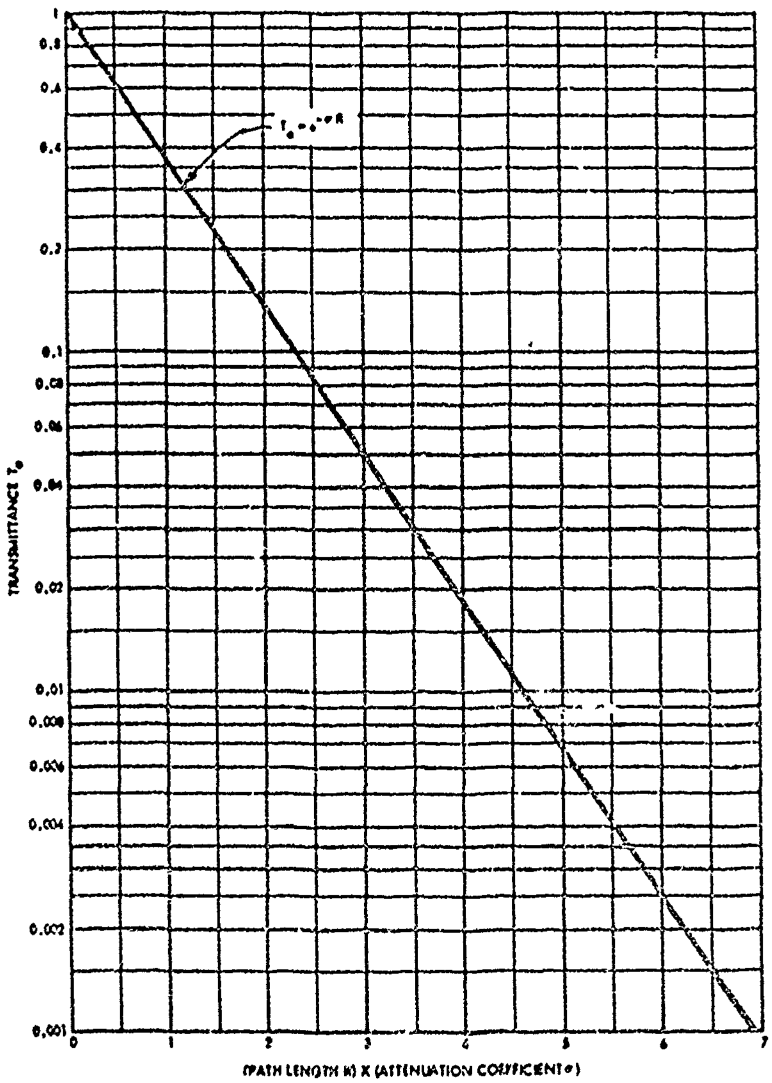


Figure 3-22. Atmospheric Transmittance as an Exponential Function of Path Length Times Attenuation Coefficient

A more exact calculation of slant path transmittance through the atmosphere can be obtained by using the data in Table 3-16 of Valley (1965) for a model of a standard, clear atmosphere; values of the "extinction optical thickness" from that table have been used to calculate the atmospheric transmittance from a point at sea-level to points at various altitudes and horizontal ranges from that point.

3.4.11 Directional Luminous Reflectance

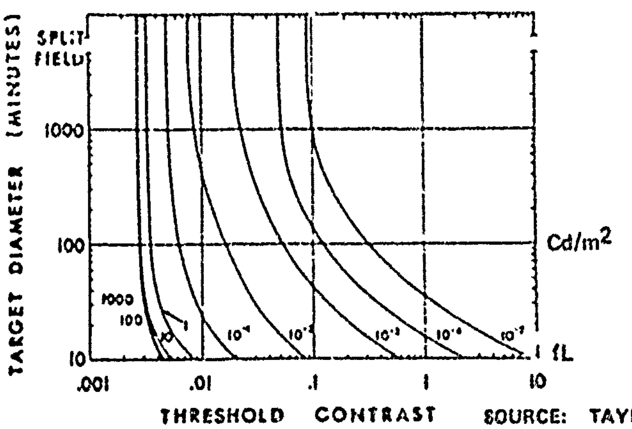
Reflectance is the intensity of light reradiated from a surface. Gordon (Duntley, et al., 1964) provides tables of directional luminous reflectances for terrain at various azimuths of the path of sight relative to the sun, reflectances of objects also at various sun/zenith and sun/LOS angles. The data in these tables may be used to compute target/background contrasts (inherent) which can be decreased by the use of atmospheric transmission coefficients for determining the visibility ranges of targets relative to threshold contrast requirements.

3.4.12 Practical Detection Probability Prediction (Field Effects)

Taylor (Duntley et al., 1964) provides a table of threshold contrast as a function of the target size, which is reproduced as Table 3-VI. When using tables such as this one, or curves containing similar data, to determine visibility of the target, field factors (Figures 3-23, 3-24, 3-25) are used which bring these contrast requirements out of the laboratory and into the real world of practicality. Taylor also presents a table, reproduced below as Table 3-VII, which indicates the field factors which should be used to account for location relative to the visual field, knowledge of the time of target occurrence, target size, and knowledge of the duration of the target in the field of view. These field factors also adjust from a 0.50 probability (threshold) to a 0.95 probability or certainty (acquisition) that the target is seen. These conversion factors are required if the laboratory threshold requirements are to be maximally useful and correct in calculating visibility functions.

If a design engineer wishes to use laboratory data such as Figure 3-26 for finding a realistic estimate of observer performance under field conditions, he makes adjustments as shown in the following example.

Assume that an observer must confidently detect the occurrence of a stimulus of known duration and size but of unknown location within a circular display area with a diameter of 8 degrees visual angle. The target will be present at infrequent intervals, say once every 15 minutes or so, and he can be allowed to miss only 5 percent of the occurrences. The observer is new to the task, and the task is to arrange the contrast of the target so that this 95 percent criterion will be met. Laboratory data show that for the specified target size and duration and for the prevailing adapting luminance, the required contrast for 50 percent correct discrimination by practical observers in a forced-choice experiment was found to be 0.0061 (Figure 3-26). To correct, respectively, for confidence level (Table 3-VIII), unknown location, vigilance (see paragraph 3.4.12.1), and lack of training (paragraph 3.4.12.1), multiply the basic contrast threshold value by 1.64, 1.31, 1.19, and 2.00, i.e., by 5.12. The needed target contrast, therefore is 0.031 in this problem. Note that this estimate brings the probability into the operational range, i.e., the 0.95 confidence level, from a basis in forced choice experimental threshold data. An additional correction factor of 1.2 is sometimes added to the total factor as a multiplier of the basic threshold contrast to approximate ordinary seeing. To use laboratory threshold data from "yes-no" experiments, a rough rule of thumb is sometimes to double the liminal contrast value rather than itemize each correction factor separately.



fL	Cd/m^2
1000	3426.0
100	342.6
10	34.3
1	3.43
10^{-1}	.34
10^{-2}	.03
10^{-3}	.003
10^{-4}	.0003
10^{-5}	.00003

Figure 3-23. Threshold C Function of the Diameter Circular Target. This f extension of the Tiffany upon experiments by Tayl assumed that asymptotic contrast would be reached of a "split field", i.e target of infinite radi curve is a different a luminance level

TABLE 3-VII

Contrast Correction Factors to be Applied when Deprived of Knowledge of Various Target Pro

Target Properties			
Location ± 4 degrees or more	Time of Occurrence	Size (3 used)	Duration (3 used)
+	+	+	+
+	−	+	+
+	−	+	−
+	−	−	+
+	−	−	−
−	+	+	+

*+, knowledge; −, lack of knowledge. Adapted fr (1958, 1959).

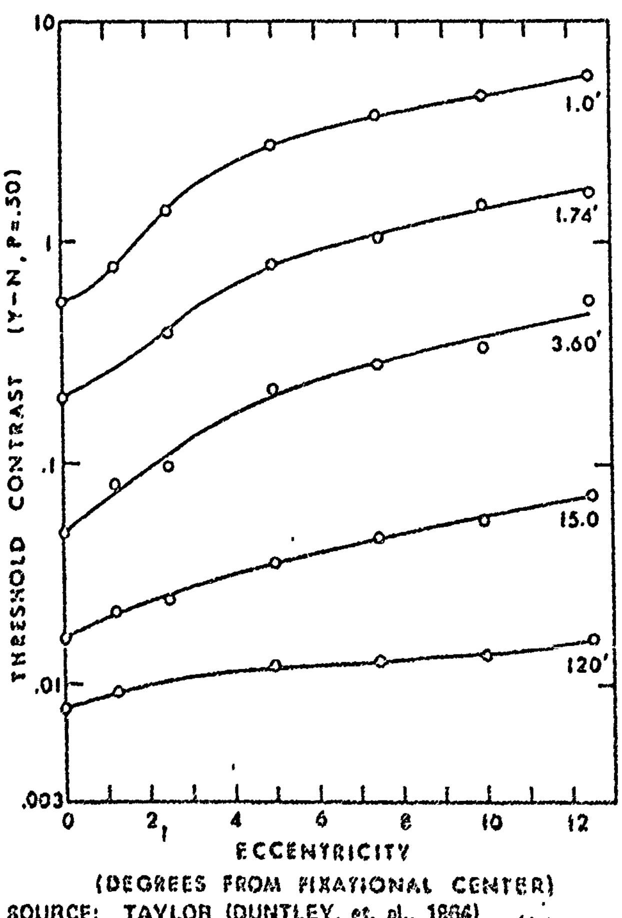


Figure 3-24. Threshold Contrast as a Function Position and Target Size for Binocular Photopi An adaptation level of 75 ft-L (257 cd/m^2) and duration of 0.33 seconds were used. The numbe is the angular diameter of the uniform circula Each data point is based upon 2400 observa (4 observes).

Th   iold Contrast as a
the Diameter of a Uniform
rget. This figure is an
f the Tiffany data based
ments by Taylor. Taylor
: asymptotic values of
ld be reached in the case
: field", i.e., with a
infinite radius. Each
a different adaptation
minance level.

VII

e Applied when Observer is
iou   get Properties*

s		
e ed)	Duration (3 used)	Correction Factor
	+	1.0
	+	1.40
	-	1.60
	+	1.50
	–	1.45
	+	1.31

ge. Adapted from Blackwell

is a Function of Retinal
cular Photopic Vision.
57 cd/m^2) and a target
d. The number of each
uniform circular stimuli.
: 2400 observations

TABLE 3-VI

Values of Threshold Contrast as Function of Target Diameter
for Stimulus Duration of 0.33 sec*

Target Diameter (min of arc)	Threshold Contrast	Target Diameter (min of arc)	Threshold Contrast	Target Diameter (min of arc)	Threshold Contrast
120.0	0.00763	2.75	0.0396	1.08	0.200
82.5	0.00785	2.70	0.0404	1.06	0.207
62.5	0.00810	2.61	0.0422	1.04	0.213
51.0	0.00835	2.55	0.0435	1.03	0.220
43.5	0.00860	2.49	0.0450	1.02	0.226
37.0	0.00890	2.43	0.0464	1.00	0.233
32.5	0.00915	2.39	0.0478	0.990	0.240
29.5	0.00940	2.33	0.0492	0.975	0.248
23.5	0.0100	2.29	0.0504	0.960	0.256
21.5	0.0103	2.24	0.0522	0.945	0.264
19.0	0.0107	2.19	0.0541	0.930	0.272
17.5	0.0110	2.15	0.0558	0.920	0.280
16.5	0.0113	2.11	0.0573	0.905	0.288
15.0	0.0117	2.06	0.0592	0.890	0.297
14.2	0.0120	2.03	0.0610	0.880	0.306
13.2	0.0124	1.99	0.0630	0.865	0.316
12.5	0.0127	1.95	0.0650	0.855	0.326
11.5	0.0132	1.92	0.0670	0.840	0.337
10.8	0.0136	1.88	0.0690	0.830	0.347
10.2	0.0140	1.85	0.0710	0.815	0.358
9.70	0.0144	1.82	0.0735	0.805	0.369
9.10	0.0149	1.78	0.0760	0.790	0.380
8.70	0.0153	1.75	0.0780	0.780	0.392
8.20	0.0158	1.73	0.0800	0.765	0.405
7.80	0.0163	1.70	0.0830	0.759	0.415
7.40	0.0168	1.67	0.0855	0.745	0.428
7.00	0.0174	1.64	0.0883	0.735	0.442
6.75	0.0179	1.61	0.0910	0.725	0.455
6.45	0.0184	1.58	0.0940	0.713	0.470
6.10	0.0191	1.56	0.0965	0.701	0.485
5.90	0.0196	1.53	0.100	0.692	0.500
5.65	0.0202	1.51	0.102	0.682	0.515
5.40	0.0208	1.48	0.106	0.671	0.530
5.15	0.0216	1.46	0.108	0.660	0.550
5.00	0.0222	1.44	0.112	0.651	0.565
4.80	0.0229	1.42	0.116	0.642	0.583
4.60	0.0236	1.39	0.119	0.633	0.600
4.45	0.0243	1.38	0.122	0.622	0.620
4.30	0.0251	1.35	0.127	0.615	0.635
4.15	0.0258	1.33	0.131	0.604	0.660
4.00	0.0267	1.32	0.134	0.596	0.680
3.90	0.0275	1.29	0.138	0.588	0.700
3.75	0.0283	1.27	0.143	0.579	0.720
3.65	0.0292	1.25	0.148	0.569	0.745
3.50	0.0301	1.23	0.152	0.560	0.770
3.41	0.0311	1.21	0.157	0.552	0.795
3.32	0.0320	1.19	0.162	0.545	0.815
3.22	0.0331	1.18	0.166	0.537	0.840
3.15	0.0341	1.16	0.172	0.528	0.870
3.07	0.0352	1.14	0.178	0.519	0.900
3.00	0.0362	1.12	0.183	0.512	0.925
2.90	0.0373	1.11	0.189	0.505	0.950
2.82	0.0384	1.09	0.195	0.497	0.985

Source: Taylor(Duntley et al., 1964).

*Binocular viewing, foveal fixation, and forced-choice temporal method. Values are averages from large-scale plots of four observers, and hence represent smoothed data.

2

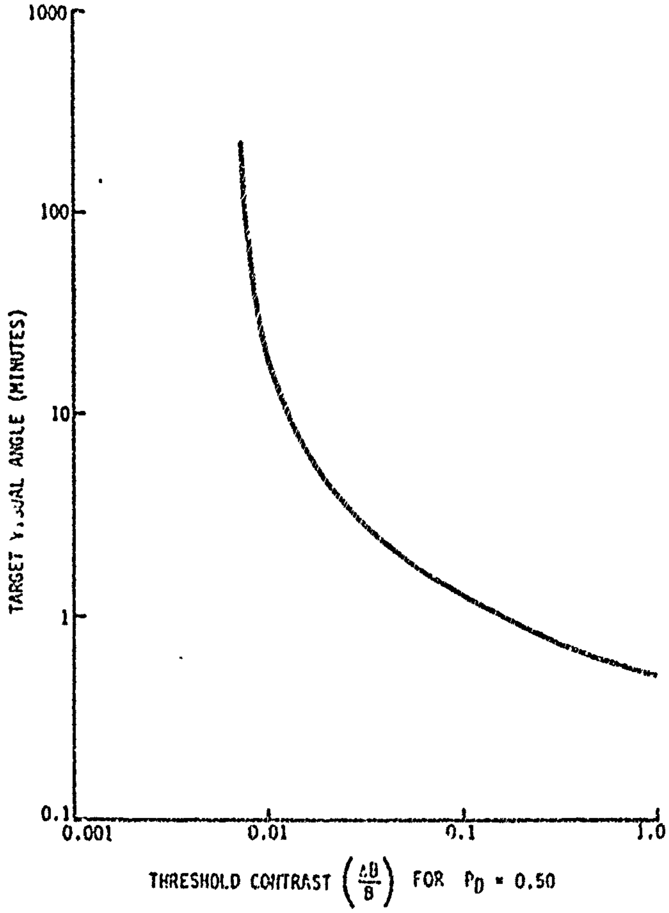


Figure 3-25. Redetermination of the Target Size and Threshold Contrast Dependency Made Under Controlled Conditions of Central Foveal Fixation and an Invariant Target Duration of 0.33 Sec. Background luminance constant at 75 ft-L (257 cd/m²). The forced choice temporal psychophysical method was used, and the data represent averages from five observers who made a total of 45,000 observations, using eighteen target sizes (see Table 3-VI).

Figure 3-26. Contrast Transmittance Nomogram

INHERENT BACKGROUND LUMINANCE

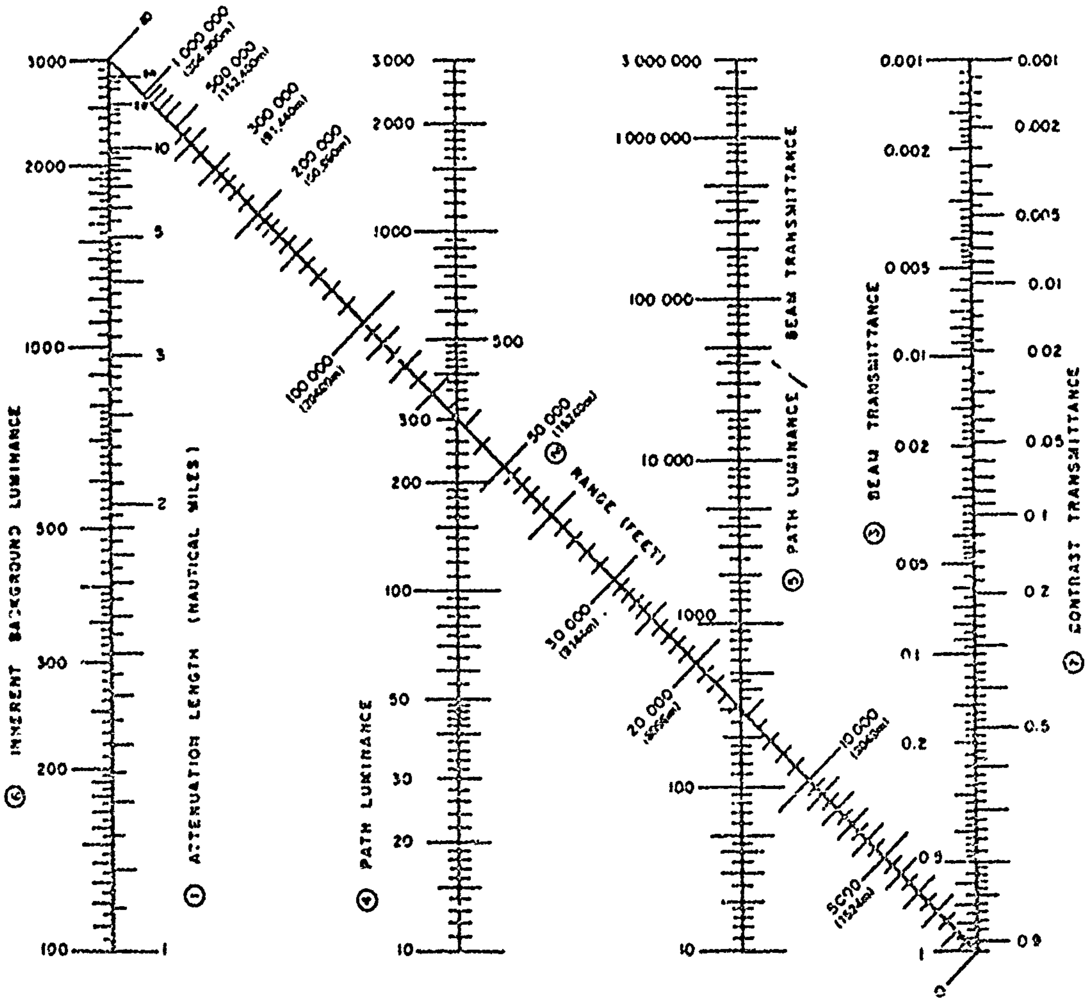


TABLE 3-VIII

Probability Conversion Factors (Confidence Level)

To Obtain Detection Probability	Multiply Value of Contrast at P = 0.5 by
0.90	1.50
0.95	1.64
0.99	1.91

3.4.12.1 The Effects of Training on the Contrast Threshold

A study by Taylor (1964) indicated the character of the practice effects found in a simple laboratory detection experiment, and showed that a correction factor of 1.90 in contrast will compensate for the difference between trained and naive observers. This value is in excellent agreement with the factor reported by Blackwell (1959) of 2.00 for a different data collection method.

The correction factor needed for vigilance is task-dependent; Jerison and Pickett (1963) should be consulted. Taylor recommends a contrast correction factor of 1.19 for vigilance use generally, as does Blackwell (1958).

Additional contributions to the field factor may occasionally occur. These tend to be even more highly individual, and generally derive from special environmental conditions and observer states, e.g., oxygen deprivation, dietary factors, acceleration, vibration, fatigue, distraction, toxic atmospheres, glare, anxiety, sensory deprivation, abnormal thermal levels, and a host of others. Only fragmentary data can be adduced in most cases, and it is commonly found necessary to assess these effects by means of specific experiments.

3.4.13 Contrast Transmittance

Boileau (Duntley et al., 1964) provides tables, equations, graphs and a nomogram for determining the relative visibility of objects at different altitudes and at different sun azimuths. He uses the equivalent attenuation length method of Elterman (1963) to account for the atmospheric attenuation variation with altitude along inclined paths of sight. Duntley (1946, 1948) handles this problem by means of his optical slant range concept. Duntley, Boileau and Preisdendorfer (1957) prefer the summation of attenuation length profile method. Boileau first computes the beam transmittance by means of the equation:

$$T = \exp \left\{ - \left[Z/\bar{L}(z) \right] \sec \theta \right\}$$

This determines beam transmittance between sea-level and altitude. $\bar{L}(z)$, the equivalent attenuation length is obtained by measured data summarized in Table 3-IX. Using tables included in that article, he then determines the sky luminances for inclined paths of sight ranging from the vertical (zenith angle 0 degree) to horizontal (zenith angle 90 degrees) with respect to the sun of 0, 45, 90, 135, and 180 degrees azimuth angles. Using Duntley's equation for apparent luminance of an object seen through the atmosphere:

$$B_r = B_o T_r + B^*$$

$$B^* = \text{path luminance}$$

which says that path luminance is equal to the difference between the apparent luminance and the product of the inherent luminance and the beam transmittance, he then states that the path luminance for a path of sight between two altitudes is the difference between the path luminance at the

observer's altitude (obtained from the appropriate table) and the product of the path of sight beam transmittance and the path luminance at the object altitude.

TABLE 3-IX

Measured and Equivalent Attenuation Lengths, and Ratios of Altitude to Equivalent Attenuation Length

Altitude, z		Measured $L(z)$[a]		Equivalent $\bar{L}(z)$[b]		
(ft)	(km)	(nmi)	(km)	(nmi)	(km)	$z/\bar{L}(z)$
0	0	4.60	8.52	4.60	8.52	0.000
1000	0.305	1.50	2.78	2.65	4.91	0.062
2000	0.610	0.40	0.74	1.75	3.24	0.188
3000	0.914	3.10	5.74	1.71	3.17	0.289
4000	1.219	7.00	12.97	1.96	3.63	0.356
5000	1.524	22.0	40.77	2.32	4.30	0.354
6000	1.829	28.5	52.82	2.74	5.08	0.361
7000	2.134	31.0	57.45	3.15	5.84	0.365
8000	2.438	34.0	63.01	3.55	6.58	0.371
9000	2.743	17.5	32.43	3.92	7.26	0.378
10000	3.048	19.5	36.14	4.25	7.88	0.387
11000	3.353	21.5	39.84	4.58	8.49	0.395
12000	3.658	22.5	41.70	4.90	9.08	0.403
13000	3.962	26.5	49.11	5.22	9.67	0.410
14000	4.267	31.5	58.38	5.54	10.27	0.416
15000	4.572	30.0	55.60	5.86	10.86	0.421
16000	4.877	34.5	63.93	6.18	11.45	0.426
17000	5.182	34.0	63.01	6.48	12.01	0.431
18000	5.486	38.0	70.42	6.80	12.60	0.436
19000	5.791	39.0	72.27	7.10	13.16	0.440
20000	6.096	35.0	64.86	7.40	13.71	0.445
25000	7.620	44.9	83.21	8.85	16.40	0.465
30000	9.144	53.8	99.70	10.3	19.09	0.481
35000	10.668	64.9	120.27	11.6	21.50	0.495
40000	12.192	81.7	151.41	13.0	24.09	0.507
45000	13.716	104	192.73	14.4	26.69	0.515
50000	15.240	132	244.63	15.8	29.28	0.522
55000	16.764	168	311.34	17.1	31.69	0.528
60000	18.288	214	396.58	18.5	34.28	0.533
100000	30.48	262	485.54	29.9	55.41	0.550
200000	60.96	274	507.77	59.3	109.89	0.551
∞	∞	∞	∞	—	—	0.551[c]

[a]Attenuation length $L(z)$ was recorded continuously as a function of altitude from 6.096 km to 0.305 km during descent of airplane at 305 m per min, with the zero altitude value recorded simultaneously in an instrumented van beneath the flight pattern. Attenuation lengths above 6.096 km are extrapolated, using density ratios calculated from Minzner et. al., (1959).

[b]The quantity $1/\bar{L}(z)$ is equal to Elterman's mean attenuation coefficient $K_a(h)$, and the two quantities $z/\bar{L}(z)$ and $K_a(h)\cdot h_1$ may be used interchangeably. See Elterman (1966).

[c]The value of $z/\bar{L}(z)$ where $z = \infty$ was calculated from the sea level to space transmittance obtained from measured and extrapolated attenuation length data.

Source: Boileau (Duntley et al., 1964).

Once the beam transmittance and the path luminance have been found for the assumed path of sight, the apparent luminance B_r of an object having an inherent luminance of B_o can be readily predicted by the above equation. To detect targets against a ground cover background, Boileau shows how the directional luminance reflectances given in Gordon (Duntley, et al., 1964) can be used together with the sky luminance he gives. The directional luminous reflectance of objects also given in Gordon can be used when man-made objects must be detected against terrain backgrounds. The ratio of the apparent contrast to the inherent contrast is called the contrast transmittance. It may be calculated from the beam transmittance, the inherent and apparent background luminance. Figure 3-26 constructed by Jacqueline I. Gordon can be used to quickly determine (a) the beam transmittance for a horizontal path of sight from the attenuation length and range and (b) the ratio of path luminance to beam transmittance from the two or (c) the contrast transmittance from this ratio and the inherent background luminance. It solves the following equation:

$$C_r/C_o = (1 + B^*/T_R\, B_h)^{-1}$$

The contrast transmittance applies to any object which may appear against the prevailing background and has therefore been specified as universal contrast transmittance since it does not involve any photometric property of the object.

3.5 Summary

Chapter 3 has summarized the effects of scene and flight geometry, target and background features and characteristics, and the effect of atmospheric conditions on target acquisition. All of these factors are shown to be important in determining the ranges at which targets can be detected, recognized and acquired. Chapter 4 will discuss the effects of the display parameters and design on target acquisition.

CHAPTER FOUR

IMAGING SYSTEM CHARACTERISTICS

4.1 Introduction

One increasingly important aspect in the study of air-to-ground target acquisition is the role of imaging systems, such as low-light-level television, forward-looking infrared scanners, high-resolution radar systems, laser line scanners and others. In any such system where information about the world is displayed to the observer, it is desired that whatever information the system is capable of receiving will be presented to the observer in an optimal fashion. Much of the research concerned with this problem has been devoted to studying relationships and tradeoffs among various parameters, with the goal of maximizing the observer's chances of acquiring the target. The purpose of this chapter is to discuss a wide variety of imaging system parameters that have been investigated in the context of air-to-ground target acquisition, and are considered to be of some importance in affecting the detection, recognition, or identification of targets.

The primary goal of this chapter is to present information that will be useful to system engineers. In order to meet this objective the review of experiments is selective. No attempt is made to review all studies dealing with a particular topic, for such an approach would be unnecessarily redundant in some cases, and chaotic in others. The dilemma that arises from attempts to be selective is that the result is often simplistic, with conclusions being stated with far more authority than they deserve. To avoid this fate, an attempt is made to present a spectrum of results, including in some instances studies that had essentially negative findings. Studies are tied together by suggesting whenever possible why different results were obtained, and by stressing that a variety of factors always operate together to produce a given level of performance. When summary graphs and charts are provided, the attempt is always made to provide enough background information so that the data will not be applied hastily or without careful thought. In short, this chapter provides to designers (a) the knowledge of the kinds of factors that have to be considered before arriving at a design decision; and (b) the best and most relevant data presently available that can aid in this decision.

Workers engaged in basic and applied research in the areas covered should also find this chapter useful, for it points out where data are particularly lacking, where conflicts should be resolved by further experimentation, and where findings need to be confirmed and extended.

Topics not to be covered in any detail here include the technical aspects of sensing/display systems, and those display design considerations which are not directly pertinent to the target acquisition problem. Readers interested in the former topic should consult such sources as Biberman and Nudelman (1971), Fink (1957), Poole (1966), and Luxenberg and Kuehn (1968). The latter topic is amply covered by such authors as Semple, et al. (1971), Carel (1965b), and Ketchel and Jenney (1968). It should also be noted that this review is heavily oriented toward television systems. This is understandable since TV research accounts for the great majority of studies to date concerned with air-to-ground target acquisition via imaging systems. Much of the information presented, however, is equally applicable to problems of infrared imaging systems, or high resolution radar. Some works specifically oriented toward the special problems of IR systems are those by Lloyd (1973) and Biberman (1971).

Most of the research results are presented in the following section (Section 4.2). Each of a number of imaging system parameters is discussed, and data pertinent to problems of target acquisition are presented. Section 4.3 then discusses two comparatively recent summary measures of image quality that show promise as means of predicting performance and providing meaningful comparisons between systems. Finally, Section 4.4 presents a summary and conclusions.

4.2 Imaging System Parameters

4.2.1 Field of View

The choice of optimal sensor field of view (FOV) has been given considerable attention experimentally. Several factors must be considered in this selection, including anticipated altitude, speed, type and size of target being searched for, type of terrain being searched, and the nature of the mission. A sizeable number of classified studies has been conducted to determine optimal FOV in the context of particular system capabilities or mission requirements. For a good survey of the recommendations made by some of these studies, see Snyder, et al. (1967) and Hillman (1967). In addition, Hairfield (1970) presents results from a number of classified, as well as unclassified studies.

There is no single answer concerning the best FOV, even for a given set of target/environmental conditions. On the one hand, a wide FOV permits a greater amount of ground to be covered, and thus increases the probability that one or more targets will be displayed to the observer. Their displayed size, however, may be such that recognition is not possible at a reasonable operational range. A smaller FOV, hence, greater magnification, can result in increased recognition slant ranges but at the expense of a greater number of missed targets. Differences in FOV also affect the displayed velocity of the target, as well as the target dwell time on the display. With a wide FOV, angular rates of the target across the display are decreased, which can facilitate performance. Furthermore, the amount of time the target appears on the display is increased, giving the observer more time to complete his search and make his identification. On the other hand, a wide FOV displays more false

targets and increases the observer's search requirements. If the system is to be used for navigational purposes as well as for target acquisition, several studies have shown that a wide FOV is preferable to a relatively narrow one (e.g., Leininger, et al. 1963, Williams, et al. 1965, Kinder and Stedman, 1970). Thus, there are several opposing factors that must be weighed.

The following pages present the results from several representative experiments, illustrating the nature of those tradeoffs to be considered by system designers.

One important study showing the tradeoff between the likelihood of recognizing the target at all versus the likelihood of recognizing it at a greater distance was conducted by Rusis and Snyder (1965). They investigated three TV camera FOV's with the following vertical X horizontal dimensions: 25° X 34°, 7.5° X 10°, and 6.2° X 8.2°. Their results are shown in Figure 4-1. It may be seen that 10% of the targets (for example) can be recognized at about twice the slant range for the smallest FOV as compared with the largest FOV. On the other hand, only about 55% of the targets were ever recognized with the narrow FOV, as compared to almost 90% for the large FOV. This difference would be even more striking if one were to consider that many potential targets never would have been seen at all by the narrow FOV sensor.

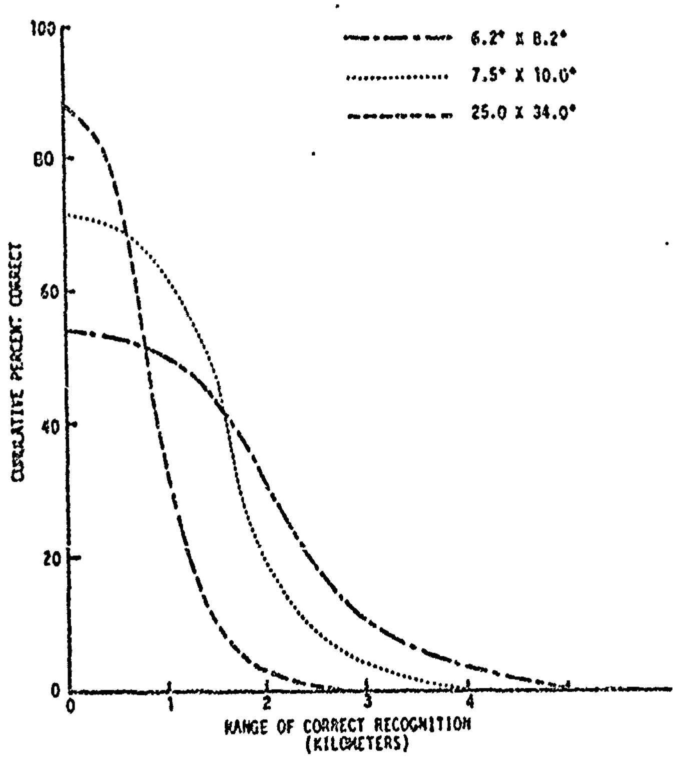


Figure 4-1. The Effect of Camera Field of View on Target Recognition Performance (data from Rusis and Snyder, 1965)

Similar results were obtained by Wyman, et al. (1966), who found that as horizontal FOV decreased from 50° to 20°, the mean range for correct recognition increased from 5200 ft. to 10,500 ft. (1,585 to 3,200m) while total target recognition probability decreased from 0.68 to 0.52.

Humes and Bauerschmidt (1968) also found results in essential agreement with those presented above.

Thus it can be see that the choice of FOV depends in part on the nature of the mission and the number of targets expected to be encountered. On a mission where targets of opportunity are plentiful, and detection at a long range is necessary in order to achieve a high kill probability, a relatively narrow FOV is indicated. On the other hand, if the mission requirements dictate that it is important to allow few, if any, targets to go undetected, then a wider FOV is appropriate.

The results of a study of Ozkaptan, et al. (1968), however, suggest that the above generalization must be qualified somewhat. They investigated acquisition performance under four FOV's ranging from 14.48° to 4.85° horizontally. They found that FOV had no effect when subjects were prebriefed as to location of the target, but that without such briefing, detection probability was greatest with the smallest FOV. This result, however, was probably the result of their particular experimental approach; the targets were tracked automatically so as to be within the FOV throughout each trial. Thus, under greatest magnification (i.e., when FOV is smallest) the target was large enough for detection early in the run. Application of these results should therefore be restricted to cases where it is assumed some cueing system (e.g., radar or navigational) has enabled the target to be brought within the sensor FOV.

A study by Simon and Craig (1965) sought to segregate the opposing effects of increased magnification and decreased observation time as a result of decreasing FOV. The purpose was to determine the tradeoff between these two factors. The subject's task was to search for airfields in photographs simulating a telescopic view of the earth from a height of 325 kilometers. Performance was found to improve as both magnification and observation time increased, and image movement rate decreased. When a change in the magnification power was inversely proportional to changes in observation time and image movement rate, magnification power was found to be the more potent variable. Its possible effects more than offset the negative effects of decreased observation time and increased movement rate. The authors note that this result is reasonable when one considers that increasing magnification by a factor of 2 decreases observation time by the same factor, but increases the ratio between target area and displayed background area by a factor of 4. To some extent, the results are specific to this experiment, since target movement was never allowed to exceed 30 degrees/second, a rate beyond which acuity begins to decrease because of visual blur (cf, Snyder and Greening, 1965). If higher rates had occurred, this variable may have counteracted the beneficial effects of increased magnification.

The results of studies such as these, showing that any one FOV has both advantages and drawbacks, have led many to recommend that variable FOV's

be utilized. Several methods are available for providing multiple FOV capability. A field study by Heap (1965) (reported by Parkes, 1972) has provided some support for the concept of a continuously variable FOV (i.e., a zoom lens). Some performance improvement was found when a zoom lens was compared with the corresponding fixed-focal-length lens. Hillman (1967) has noted, however, that adequate experimental justification for the zoom lens concept has not yet been provided. Drawbacks to a zoom system include the need for frequent adjustments and the loss of resolution while the FOV is changing.

Greater support has been given to the dual FOV approach. For example, Carter (1962) found that in an evaluation of low-light-level TV systems, all operators tested preferred having a wide FOV for search, with the capability of switching to a narrow FOV for recognition. Humes and Bauerschmidt (1968) point out that the optimal FOV changes as a function of other variables, and therefore should itself be permitted to vary. For example, as the camera depression angle increases, the optimal FOV increases. In addition, even if the depression angle were fixed, it was found that aircraft velocity/height ratio (V/H) interacted with FOV, so that under low V/H increasing the magnification improved recognition probability, while for a high V/H the opposite occurred. Thus, in order to ensure the best possible performance under varying speeds and altitudes, it seems highly desirable to permit the observer to choose between at least two FOV's.

A unique approach in providing variable FOV capability was investigated by Wyman and Sturm (1966). They studied a dual-TV system in which the observer was presented with a wide (28° horizontal) and a narrow (5°) FOV scene simultaneously. The observer could select that portion of the wide FOV that he wished to magnify. The results were predictable on the basis of the data already presented in this section. In comparison with a fixed wide-FOV system, the dual system reduced recognition time significantly, due to the ability to magnify the area in which a suspected target appears. Recognition probabilities, however, were not affected, which is reasonable since it has been shown that a wide FOV improves the likelihood of target recognition. This result may also have been due to the nature of the test, which produced high recognition rates (over 90%) under both conditions. It should be mentioned that the experimental conditions did not represent an air-to-ground search situation, but rather the recognition of motor vehicles on a freeway. Thus, this approach, while suggestive, should be verified with a more representative task.

The preceding discussion has presented some general considerations to be weighed when deciding upon the FOV to recommend for a system, or when deciding between a fixed vs. a variable FOV. It has been seen that a variety of factors must be taken into account, and tradeoffs must be established. The remainder of this section will present a discussion of the means for determining the FOV requirements in order for a target to be detected, recognized, or identified, under a particular set of circumstances. Assuming that the target is within the FOV, it may be important for a system designer to know the minimum amount of magnification that is necessary in order for a particular task to be carried out. Several variables are interrelated, and it is possible to solve for any one if the others are

known or assumed. These variables are: total system resolution, FOV, target size, distance from the target and number of resolution lines required across the target. Typically, designers would be interested in solving either for maximum permissible FOV or minimum required system resolution.

The maximum FOV at which a particular operation could be carried out (e.g., detection, recognition, identification) may be approximated by the following formula:

$$FOV = \frac{L \cdot 57.3}{R} \cdot \frac{T}{n} \qquad (4.1)$$

where,

FOV = field of view (in degrees)

L = total system line number (a measure of system resolution, expressed as a number of TV lines per picture height)*

R = range to target (in meters)

n = required number of TV lines across the minimum dimension of the target

T = target size across minimum dimension (in meters).

It may also be desirable to calculate the minimum system resolution (L) required for target acquisition when a particular FOV is assumed. In that case, the formula is:

$$L = \frac{FOV \cdot R}{57.3} \cdot \frac{n}{T} \qquad (4.2)$$

Before illustrating the use of these formulas, it is necessary to discuss briefly two of these terms, L and n. As stated, L, which is the total line number of the system, is one measure of system resolution (for a discussion of additional measures, see Section 4.2.2). In practice it may be determined by finding a pattern of black and white lines (i.e., a square-wave pattern) in which the lines are just wide enough so that an observer can distinguish them when they are presented through the TV system being evaluated. The number of lines of that width that would fit from top to bottom of the display is then determined, and this number is L. It should be noted that although this measure of resolution is widely accepted, in practice it is not always an entirely objective measure, since observers will disagree to some extent as to when the pattern is no longer distinguishable.

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* The reader is reminded that 2 TV lines equal one black and white line, or one optical line pair.

With regard to n, the required number of TV lines across the target, this is an empirical measure that has been determined for a certain class of targets and under certain conditions by Johnson (1958). It is remarkable, considering the number of times the so-called "Johnson criterion" has been applied (correctly and incorrectly), that further parametric studies have not been conducted to extend his findings. Because of the importance of Johnson's "equivalent bar pattern" concept, some time will be spent describing it.

The basic idea is to find a way of describing complex real targets in terms of much simpler visual patterns. Johnson placed a variety of military targets at some distance from a TV camera. Alongside these targets he placed a number of square-wave patterns, differing with respect to the width of the lines. These patterns are described in terms of the number of lines that will fit across the minimum dimension of the target (see Figure 4-2). When he had found that a particular target could be detected at a particular distance, he found the bar pattern that could be just resolved at that distance. He found that for each perceptual task, it was possible to describe performance simply in terms of the number of just-distinguishable lines that would fit across the minimum dimension of the target, and that this number was relatively independent of the particular target and the viewing distance. Table 4-I presents his results. Johnson notes that his findings were also independent of signal-to-noise ratio and contrast, provided that the contrast of the bar chart was the same as the contrast of the target itself.

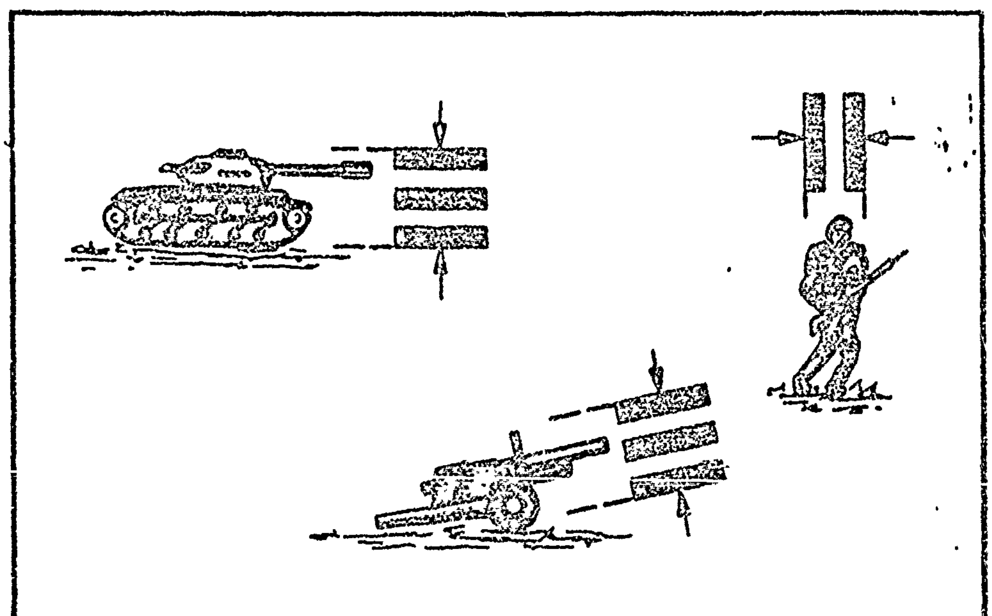


Figure 4-2. Method of Optical Image Transformation (redrawn from Johnson, 1958)

TABLE 4-I

Optical Image Transformations (adapted from Johnson, 1958)

(a) Levels of discrimination defined.

Classification of Discrimination Level	Definition
Detection	An object is present
Orientation	The object is approximately symmetric or asymmetric and its orientation may be discerned
Recognition	The class to which the object belongs may be discerned (e.g., gun, truck, man, etc.)
Identification	The target can be described to the limit of the observer's knowledge (e.g., 105mm howitzer, jeep, soldier, etc.)

(b) Johnson's criteria for required resolution.

Target	Resolution (in TV lines) per Minimum Dimension			
Broadside View	Detection	Orientation	Recognition	Identification
Truck	1.8	2.5	9.0	16.0
M-48 Tank	1.5	2.4	7.0	14.0
Stalin Tank	1.5	2.4	6.6	12.0
Centurion Tank	1.5	2.4	7.0	12.0
Half-Track	2.0	3.0	8.0	10.0
Jeep	2.4	3.0	9.0	11.0
Command Car	2.4	3.0	8.6	11.0
Solder (Standing)	3.0	3.6	7.6	16.0
105 Howitzer	2.0	3.0	9.6	12.0
Average	2.0 ± .5	2.8 ± .7	8.0 ± 1.6	12.8 ± 3.0

Upon reflection it may be seen that Johnson's criterion can be very useful. One of the principal advantages is that it may be used regardless of the resolution of the particular imaging system under consideration -- since it is in effect pegged to that resolution. For example, suppose we calculate that the image of an M-48 tank must be 8 mm high in order that 14 TV lines could fit across it in a 500-line system. If the system resolution were now cut to 250, Johnson's criterion would not change; rather, the image would simply have to be made twice as large on the same display in order for it to be identified.

In comparison, it should be noted that a somewhat similar approach has been taken by a number of researchers who have sought to determine the required number of TV scan lines to be placed across the image. Some of these studies are reviewed in Section 4.2.3; many represent valuable contributions to the literature. But it should be pointed out that in applying those results one must also have an additional piece of information -- namely, some measure of the resolution of the TV system that was employed in the studies. This information is necessary since if the resolution changes, the required number of scan lines will change as well.

It should of course be noted that applying Johnson's criteria may give good "ball park" answers, but that they will not be exact. For example, no consideration was given to oblique viewing angles -- the targets in Figure 4-2 are shown as they would be seen when straight ahead, rather than below and in front of the observer. Further experimentation could extend Johnson's findings in many ways, by exploring different viewing angles, different target backgrounds, adding time constraints, etc. A caution is also in order, which is not widely understood: as noted, Johnson's equivalent bar patterns were always of the same contrast as the targets themselves. For high contrast targets this presents no problem. But if one is attempting to apply his criterion in the case of a target that is assumed to be of low contrast, one has to redefine total system resolution, L, by adjusting it downward. Since L is normally measured with a high contrast pattern, it would result in an underestimation of the required image size, or an overestimation of the maximum FOV, when n has been determined with a low contrast pattern. What is needed is a series of graphs showing how the TV line number would change if bar patterns of various lower contrasts were employed. Another problem arises with targets that are not of uniform luminance. In such cases, contrast is not easily defined, and a bar pattern of "equivalent" contrast is, at best, arbitrary.

Let us return now to Equations (4.1) and (4.2), giving an example of how they may be used. Figures 4-3 to 4-8 (adapted from Erickson, et al - 1974) present the equations graphically for a variety of ranges (R), and show how maximum FOV or minimum L can be determined once the other parameters are known or assumed. For example, assume that a recognition range of 2 kilometers is needed against a tank that is 3 meters high. If 15 TV lines are needed for identification, T/n = .20 (and n/T = 5). Figure 4-5 shows that with a FOV of 2°, a 350-line system is needed, or that with a 600-line system, the maximum permissible FOV would be 3.4°.

4.2.2 Resolution

The subject of resolution is large and complex, and cuts across many of the other topics covered in this chapter. There is not even one good definition of what is meant by resolution; rather, there are several definitions, all of which are useful for certain applications. Many of these definitions can be related to each other, given certain assumptions. This section will cover a number of what may be called the "traditional" measures of resolution. The intention here is to define them briefly, to show how they are related to each other, and to summarize the literature relating them to target acquisition performance.

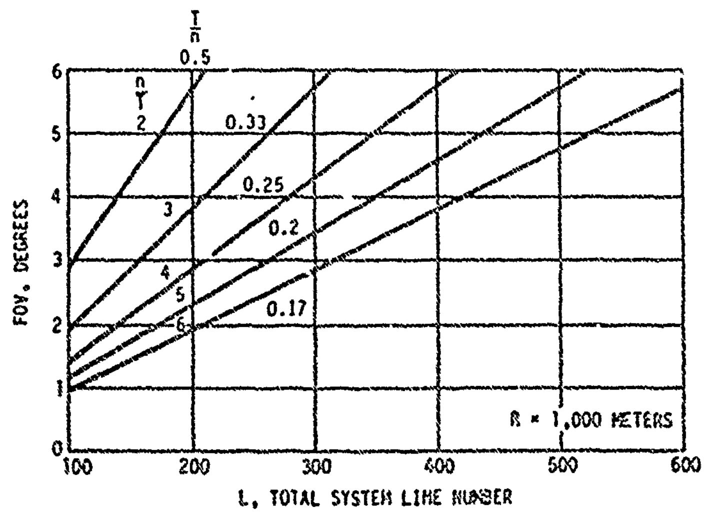


Figure 4-3. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 1 Kilometer

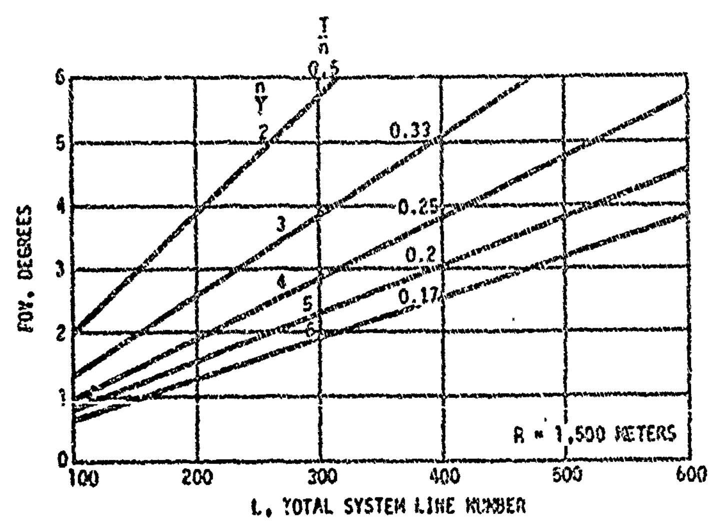


Figure 4-4. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 1.5 Kilometers

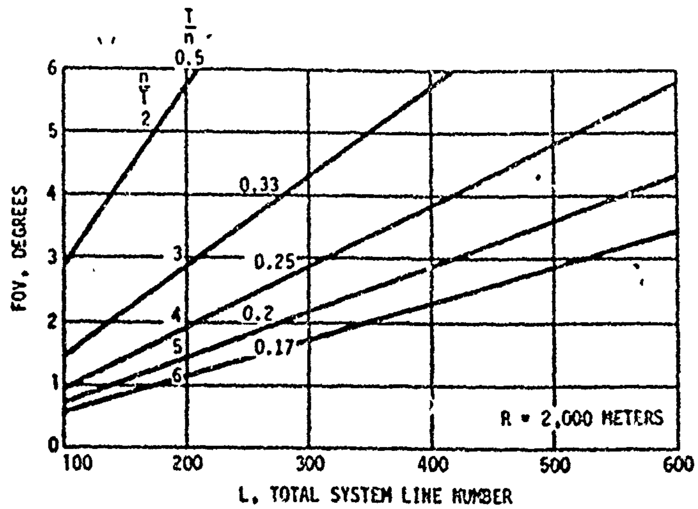


Figure 4-5. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 2 Kilometers

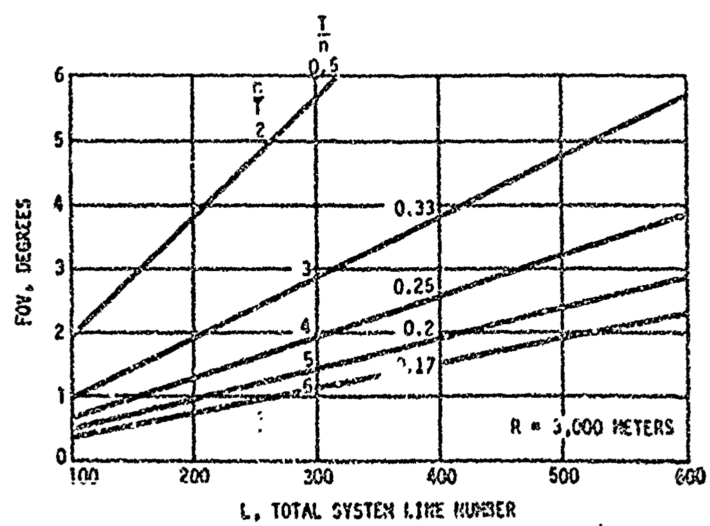


Figure 4-6. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 3 Kilometers

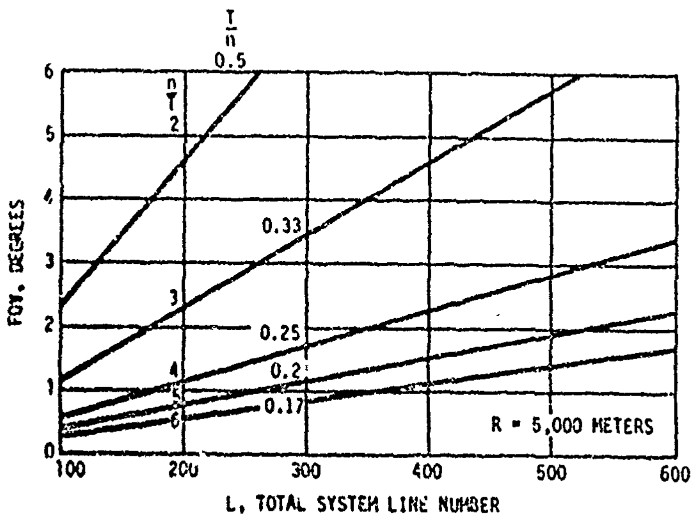


Figure 4-7. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 5 Kilometers

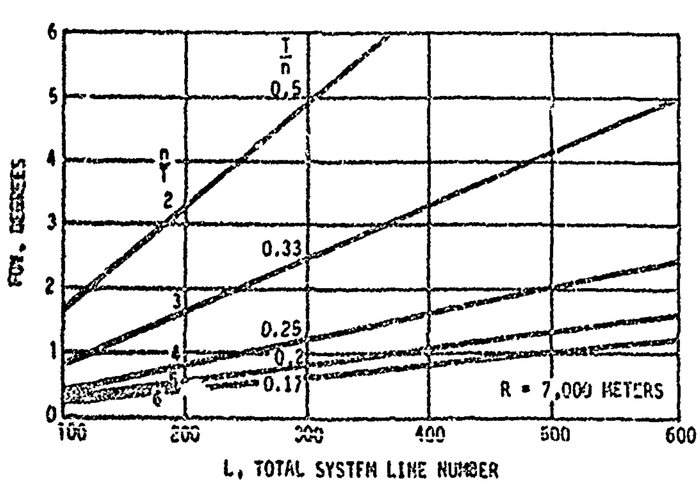


Figure 4-8. Graph of Equations (4.1) and (4.2) for Slant Range (R) = 7 Kilometers

There are several good sources available which discuss these measures in much greater detail, and no useful purpose would be served by repeating those discussions. Among recommended sources for those wishing a deeper treatment of resolution measures are Carel (1965), Semple et al (1971), and Slocum et al (1967). The first two of these sources are especially helpful for the reader who is unfamiliar with display design. They provide a good fundamental understanding of resolution measures for electro-optical systems, and of the principles on which they are based. For a discussion of other resolution measures which are applicable to thermal imaging systems, a good source is Lloyd (1973).

A later section in this chapter (Section 4.3) will present a discussion of some more recent summary measures of image quality, along with some of the experimental results available to date. Many researchers feel that these new measures may supplant some of the traditional terms, and provide a more coherent framework by which image quality may be understood.

One of the commonly employed techniques for measuring and specifying resolution for line-scanned displays is <u>shrinking raster resolution</u>. As Slocum et al (1967) describe it, the technique involves presenting a raster of equally-spaced lines on a display, and "shrinking" the spacing between these lines until the average observer can just barely perceive that lines are present. This normally occurs when there is about a 2% - 5% drop in luminance between adjacent lines. Assuming that the energy distribution in a CRT spot is gaussian (normally distributed), the line spacing when this flat-field condition obtains is approximately 2 σ, where σ is the standard deviation of the point spread function, or the radius of the spot at the point where its intensity is 60.65% of its maximum value.

Another common resolution measure is called <u>television resolution</u>, or <u>TV limiting response</u>. A square-wave bar pattern is displayed, and the spatial frequency (number of bars per linear dimension) of the pattern is increased until the observer can just detect the pattern. The limiting resolution is then expressed as the number of black and white bars discernible per unit length (such as lines per picture height, or line pairs per millimeter.) It should be noted that one square-wave cycle - i.e., one black and one white line - is referred to as 2 TV lines. If a gaussian spot is again assumed, the limiting response is reached when the TV lines are separated by a distance of 1.18σ. Thus, the number of TV limiting lines per unit distance exceeds the number of shrinking raster lines by approximately a factor of 1.7 (Slocum et al, 1967).

Another resolution measure used in television engineering is the <u>TV_{50}</u> resolution, which is based on objective measurement, rather than on the subjective criterion necessary for determining TV limiting resolution. TV_{50} resolution may be expressed as the separation between two points of light at which the intensity of the dark region between them is 50% of the intensity of their brightest points.

The 50% amplitude resolution (also known as the raster line width) is the width of a resolution element when its amplitude is 50% of its maximum level.

A resolution measure very commonly seen today is the MTF, or modulation transfer function. The MTF has been covered in some detail in Chapter 2. Briefly, it is an objective measure which describes the response of a system to a sine-wave (rather than square-wave) target; the response is expressed as the ratio of output to input modulation as a function of spatial frequency. The MTF is not as simple as some other techniques for specifying resolution, because it is not expressed as a single number. One of its useful properties, however, is that if the MTF's of all the system components are known (e.g., lens of the TV camera, video amplifier, CRT), the total system MTF is found by multiplying the MTF's of the components. The MTF can be related to some of the other resolution measures discussed above, if the spot distribution is known. If a gaussian distribution is again assumed, the relationship is that which is presented in Figure 4-9 (from Slocum et al., 1967). For example, the modulation transfer factor is 29% for a sine wave pattern whose half-cycle spacing equals the shrinking raster resolution spacing.

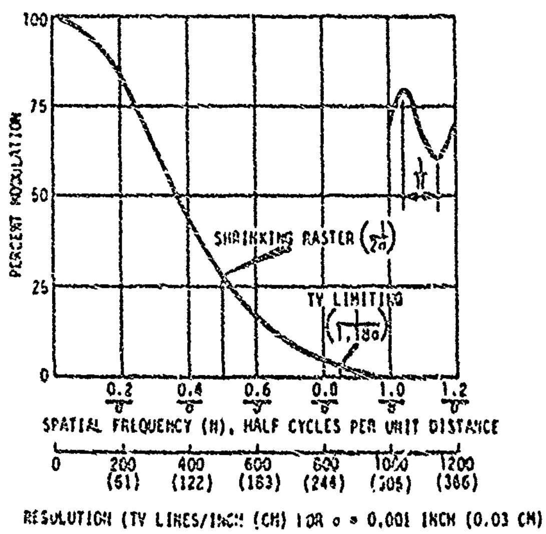


Figure 4-9. Relationship Between Relative Modulation Transfer Function, Shrinking Raster Resolution, and TV Limiting Resolution (from Slocum et al., 1967)

Still another resolution measure, proposed by Otto Schade, is the equivalent passband (N_e). N_e is related to the MTF in the following way: while MTF expresses the response of a system in one dimension, N_e is related to this response in two dimensions, and thus is based on the square of the MTF (Snyder et al., 1973). The formula is:

$$N_e = \int_0^\infty (r)^2 \, dN, \qquad (4.3)$$

where

r is the proportional sine-wave response, or modulation transfer factor, and N is the spatial frequency in TV lines/picture height.

Expressed in words, this states that N_c is the cutoff frequency for a rectangular response (perfect filter) function (one which drops abruptly from 100% to 0%), when the area of that rectangular is equivalent to the area under the MTF^2 curve. Thus the N_e measure provides a single score, which is based on the response of the system across its total operating spectrum, rather than at any particular spatial frequency.

Several of the common resolution measures can be related to each other quite readily. Tables of conversion factors have been presented by Carel (1965), and by Slocum et al (1967). Table 4-II presents the information compiled by Slocum et al. It should be noted that, since these relationships were calculated on the basis of gaussian spot distributions, they are only first approximations and may result in large errors if spot distributions are not gaussian.

TABLE 4-II

Conversion Table for Several Measures of Display System Resolution
Where σ equals the Standard Deviation
(From Slocum et al., 1967)

From		To							
		TV Limiting	10% MTF	TV_{50}	Shrinking Raster	50% Amplitude	50% MTF	Optical	Equivalent Passband
TV Limiting	1.18σ		.80	.71	.59	.50	.44	.42	.33
10% MTF	1.47σ	1.25		.88	.74	.62	.55	.52	.42
TV_{50} (3 dB)	1.67σ	1.4	1.14		.84	.71	.63	.59	.47
Shrinking Raster	2.00σ	1.7	1.36	1.2		.85	.75	.71	.56
50% Amplitude	2.35σ	2.0	1.6	1.4	1.17		.88	.83	.66
50% MTF	2.67σ	2.26	1.8	1.6	1.33	1.14		.94	.75
Optical ($^1/_e$)	2.83σ	2.4	1.9	1.7	1.4	1.2	1.06		.80
Equivalent Passband (N_e)	3.54σ	3.0	2.4	2.1	1.77	1.5	1.33	1.25	

Many authors discussing target acquisition via line scanned imagery commonly employ yet another measure of "resolution," namely the number of active raster scan lines present on a display. Often they will refer to these scan lines inappropriately as "TV lines," thus creating another source of confusion for those accustomed to specifying limiting resolution in terms of TV lines per picture height. Discussion of "resolution" in terms of raster lines is unfortunate because, as Biberman (1973) puts it: "...the number of lines in a raster of a television display with no input is identical to the number of lines on the same set with an input of high signal-to-noise ratio resulting in a clear, clean, and bright picture. The zero input, of course, produces only a clear and clean pattern of horizontal lines with no picture and no information." The attempt has been made to avoid compounding this confusion in the present report, and the topic of raster line density is covered in another section (Section 4.2.3).

Studies of target acquisition experiments which investigated some measure of resolution are very few in number. Recommendations as to minimum resolution requirements may be found in quite a few sources, but the data base for these recommendations is quite small, particularly with regard to realistic, operationally relevant experiments. A larger number of studies have been concerned with the variable of raster line density, and have sought to determine the number of scan lines required across a target for different operations. These studies are discussed in Section 4.2.3.

The work by Johnson (1958) on resolution requirements for various target acquisition tasks is widely known, and the so-called Johnson criteria are frequently consulted by designers. Johnson's work was discussed in considerable detail in Section 4.2.1, and Table 4-I presented a summary of his criteria for a variety of targets and tasks. It should again be pointed out that his data are not exact and should be applied with care. Because his approach is potentially so useful, however, a greatly expanded study along similar lines would be a valuable contribution to the field. Among the parameters to be included in such a study would be target background, viewing angle, target motion, viewing time limitations, and subjective confidence levels.

A number of studies, while not concerned with resolution as an independent variable, have followed Johnson's lead and expressed their results in terms of the number of resolution elements that must be placed across the target in order for some level of performance to be attained. Williams and Borda (1964), for example, found that between 4 and 9 TV lines were required in order to make a positive identification of simple geometric forms seen on homogeneous backgrounds. When more realistic target shapes were used, such as scale models of military vehicles and other tactical targets, recognition required between 6 and 9 TV lines, with the exception of bridges which required from 3 to 8 lines. These were high contrast targets seen on clear, uncluttered backgrounds.

A series of detection experiments using a black and white TV system was conducted by Oatman at the Army's Human Engineering Laboratories. Using a static scene, Oatman measured the probability of detecting an M-48 tank when it appeared in various sectors of the TV display.

In one experiment (Oatman, 1965a) the horizontal limiting resolution was varied from 300 to 800 TV lines, while vertical resolution did not change (875 scan lines). Detection probabilities were found to be significantly lower for the 300 line condition, but there were no differences from 400 to 800 lines. This result was thought to be due to the fact that resolution was changed in only one dimension. A second study (Oatman, 1965b), therefore varied resolution in both dimensions. One condition employed a limiting resolution in the horizontal direction of 800 TV lines, and had 800 scan lines; the other condition had a limiting resolution of 450 TV lines and employed 450 scan lines. Detection scores were significantly better in the higher resolution condition. Since only two resolution levels were used in this study, it is not possible to say whether performance would have been even better with higher resolution. Hillman (1967) points out that Oatman's studies found a critical resolution for target detection of approximately 7 - 9 TV lines across the target, with performance above 9 TV lines showing no further improvement. This is substantially higher than Johnson's criterion for detection, and corresponds more closely to his recognition criterion. A discrepancy this large is not surprising considering the many differences between these studies, although the exact reason for the discrepancy is not clear. It does, however, underscore the need for studies to extend the Johnson criteria to encompass more conditions.

Several additional studies investigating resolution have involved the presentation of abstract geometric stimuli in a totally artificial setting. While some of these studies may have contributed to our basic understanding of resolution, their inclusion here does not seem warranted. For the reader wishing to pursue this topic, Bliss (1969) discusses a number of these studies. In addition, Smith (1961) presents a series of nomographs which include (among other parameters) the effects of resolution, and which are based on data from abstract stimuli -- namely, Blackwell's "eight position search in six second" detection threshold experiments. Smith concludes that, for small targets, televisual detection range would increase up to about 600 TV lines, but that detection range for large targets is independent of resolution.

Some studies have been concerned with validating the equivalent passband (N_e) measure as a means of predicting performance in realistic tasks. Hillman (1966) points out that subjective ratings of picture sharpness correlate well with N_e. With regard to target recognition, she discusses an experiment performed at RCA which studied the recognition of military-type targets seen against realistic backgrounds. While detailed results are not presented, Hillman states that recognition performance increases as a function of N_e up to some point, and then remains independent of N_e. This result implies that beyond a certain point increases in resolution do not pay off in terms of increased operator effectiveness.

Snyder et al (1973), however, state that while N_e may be a good predictor in the case of photographic imagery, there is a serious problem limiting its usefulness in electro-optical systems, viz., the noise level of the system. It is possible for two systems with the same N_e value to have different noise levels, and this noise level has a very strong effect on operator performance.

As this review has pointed out, we are faced with a difficult set of problems when it comes to measuring and specifying image quality in a fashion that permits accurate prediction of observer performance. Although these problems are bad enough in the case of predicting performance with simple geometric shapes seen against a plain background, they are much worse in the real world. Nevertheless some progress has been made, and this section has summarized some of the studies of particular importance to military needs. Self (1969) has made some thoughtful comments concerning image quality measures relevant to performance prediction, and those comments which are especially pertinent to the present discussion are quote below:

"It is often a matter of conjecture as to what constitutes significant detail in target objects, and as to how much resolution is required to adequately record or perceive such detail. How much resolution is needed is further complicated by whether or not the detail of concern appears in an appropriate or expected part of the target.

"When measured by time to detect or recognize a target, increased resolution increases performance for awhile, but is a matter of diminishing returns. A point will be reached beyond which increased resolution does not improve performance.

"Attaining, when viewing time is unlimited, some given probability of recognizing a target by form alone, i.e., without briefing or contextual cues, requires some minimum number of resolution elements across the maximum dimension of the target. The higher the desired probability, within limits, the more resolution elements required. Identification requires more resolution than detection. The number of resolution elements required depends upon the critical details, so it is different for different target objects. Resolution required also depends upon the shape of competing nontarget objects.

"When viewing time is not unlimited the same factors must be taken into account and, in addition, the dependency of required resolution upon the time limits or desired reaction time must be taken into account.

"No matter how measured, limiting resolution in an image varies with location in the scene or image: Image-forming sensors do not resolve uniformly across the total picture. In addition, resolution in different directions at any point in a two-dimensional image is usually different.

"The significant details of a target may differ in contrast (hence in resolution) from the average contrast of the target with its immediate surrounding. The background of the significant detail may even be the target."

In summary, Ketchel and Jenney (1968) present a list of general considerations to be borne in mind when designers are establishing requirements for electro-optical display resolution. While some of these generalizations are more pertinent to the perception of symbology rather than target acquisition, per se, the entire list is reprinted below.

1. A systems approach should be taken. Attempts should be made by the designer or user of a display to determine the kinds of sensors that will be used in a given weapon system. If more definitive data are lacking, the most stringent sensor resolution problem should be identified and the rule of thumb that "display resolution should be twice that of the effective resolution of the sensor" may be applied. (Slocum et al, 1967).

2. If sensor data are lacking but mission requirements are known, an attempt should be made to relate the most stringent mission and task requirement to display capability.

3. If the above seem inappropriate, an attempt should be made to specify whether or not a TV mode will be used and what the purpose of that mode will be. The recognition of ground targets, for example, might dictate that a given level of resolution is required.

4. For those displays which provide only stylized symbology for head-down, VSD [vertical situation display] type command and attitude information, the 500 raster lines now commonly specified for such displays are probably adequate. If the addition of multisensor capability is anticipated, resolution approaching Cr.el's 1000 lines might be used.

5. If alphanumeric symbols are to be displayed, an attempt should be made to apply the findings of Shurtleff and his colleagues (1967) so that an adequate number of elements per symbol height are provided.

6. In all instances the size of a display and viewing distance should be related to Whitham's (1965) charts to determine that the planned design will not create symbol elements that are too large or so tiny that they represent an unwarranted overdesign.

4.2.3 Raster Line Effects

A substantial number of studies have been concerned with the effects of the raster lines (TV scan lines) on the perception of information via line-scanned imagery. This section will review and summarize many of these studies. Out of necessity, the coverage will be selective, and will include only those reports deemed most relevant. For a brief description of additional studies not covered here, see Hairfield (1970). There are actually two kinds of experiments that fall under the heading of raster line effects, and this section will be subdivided accordingly. In the

first group are studies concerned with specifying the number of raster lines necessary to generate the target image when a particular level of performance is desired. The second group of studies deal with the total number of raster lines that should be present in a display. Important here is a discussion of the interfering effects of the raster structure itself--in particular, the spacing between lines and the "sharpness" of the individual lines.

Scan Lines Across the Target

Turning first to the question of the required number of TV scan lines across the target, a number of investigators have explored this issue within the context of "resolution". As stated in the section on resolution (Section 4.2.2), the raster line density is sometimes taken as an index of resolution in the vertical direction. It is questionable whether raster line number should really be viewed as a resolution index, because by itself it tells nothing about the ability of a system to create a faithful image. It is for this reason that the work on this topic is summarized here, rather than in the section on resolution.

Erickson and his colleagues at the Naval Weapons Center at China Lake, California, have conducted a series of experiments on line-scanned imagery, involving both abstract and realistic targets and backgrounds. These studies have consistently demonstrated a positive correlation between target identification performance and the number of scan lines passing through the target.

In some of their early work with abstract symbols, Erickson and Main (1966) found that patterns could be located 100% of the time provided they were made up of at least 6 scan lines, but that for 80% identification accuracy 20 scan lines were required. Erickson, Main and Burge (1967) employed a different monitor and found that 90% identification accuracy was obtained with 12 scan lines per symbol.

Erickson, Linton and Hemingway (1968) conducted further studies on symbol legibility, using an 875-line TV system instead of the 525-line system employed previously. With regard to identification performance, they found that the results agreed closely with results obtained from a 525-line system, and concluded that 525-line data can be used to predict performance with other raster line densities, provided the results are expressed in terms of the number of scan lines across the target, and the angular subtense of the target at the observer's eye. The authors also reviewed the literature for a number of studies concerned with visibility of alphanumeric and geometric symbols, and found that the results ranged from approximately 4 to 12 scan lines for 90% identification performance (with angular subtenses of approximately 10-15 minutes of arc.)

Some of the work by Erickson and his colleagues on TV systems is summarized by Erickson (1971). The reader is referred to this report, not only because it is valuable as a summary, but also because it discusses much of the philosophy of human factors research with television and presents recommendations for further work.

One methodological difficulty with some studies exploring raster line spacing is that the number of lines across the target is sometimes confounded with the size of the target. This can be a serious drawback, for if one is investigating the effect of placing different numbers of scan lines across a target, the angular size of the target should be kept constant, since size would be expected to affect performance in many situations. What is required are studies that result in a plot of angular subtense of the target vs. the number of scan lines across it, for a given level of performance.

This is exactly the approach taken by Hemingway and Erickson (1969) in a study where subjects were required to identify a variety of geometric symbols. They independently varied the angular subtense of the targets (4.4', 6.0', and 10.2' of arc) and the number of raster lines per symbol height (4.8, 6.3, 7.8, 12.5, 15.5, and 25.6). The angular size of the raster lines varied directly with the angular size of the targets, and inversely with the number of raster lines per symbol height. The results demonstrated that, over a certain range of values, a tradeoff exists between angular size and the number of lines across the target. If the target got smaller in angular subtense, the same level of performance could be achieved by increasing the number of scan lines across it. The authors combined their data with the data of other researchers and arrived at the composite curves shown in Figure 4-10. Three curves are shown for 80%, 90%, and 95% correct identification. (Incidentally, these curves are not really asymptotic. If they are extended further along the abscissa, they eventually will begin to rise because as the angular subtense of the target keeps increasing, so does the subtense of the raster lines. Before long, the raster structure itself will begin to interfere with perception of the target. (This effect can be observed by anybody who gets too close to a TV screen).

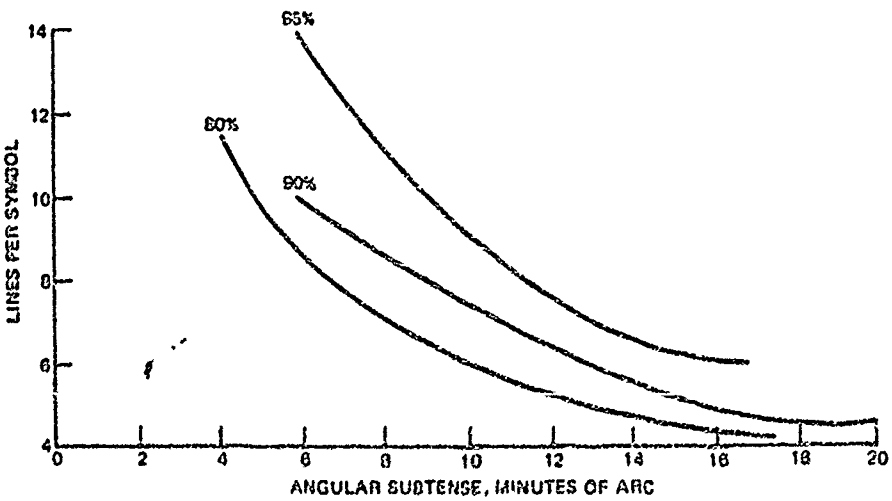


Figure 4-10. Summary of Symbol Legibility Performance at 80, 90, and 95% Correct (from Hemingway and Erickson, 1969)

This approach was continued and extended by Erickson and Hemingway (1970b) in experiments involving images of military vehicles. The stimuli were photographs of vehicles seen against either an unstructured, sandy, or foliage background. Unfortunately, the results were not as simple as the tradeoffs presented in Figure 4-10, especially for targets seen against natural terrain. For a high probability of correct identification to be assured, the vehicles had to subtend at least 14' of arc, and to be comprised of at least 10 scan lines. Further research of this nature should result in sufficient data to construct curves for realistic targets similar to those shown in Figure 4-10 for abstract stimuli.

Other studies have explored the effects of number of scan lines, but not the tradeoff between scan lines and angular size. Some of these studies are briefly described below.

Brainard, Hanford and Marshall (1965) studied the identification of scale model targets (storage tanks, bridges, buildings and aircraft) seen against realistic backgrounds. Cumulative identification probability was nearly a linear function of the number of scan lines. For 90% correct identification, between 7 and 10 scan lines were required with the particular TV system and test conditions they employed. Target size was correlated with number of scan lines, however, which may have compromised the results to some extent.

Levine, Jauer and Kozlowski (1969) studied identification of aircraft scale models viewed against a plain background, and found that 12 scan lines were required for 80% identification accuracy. Further increases to 20 scan lines resulted in no further improvement. In a later study, Levine et al (1970) studied observer performance with a TV display of high resolution aerial reconnaissance photographs. In this study they varied both the scan lines across the target, and the signal-to-noise ratio (SNR). They found that performance improved as a direct function of both of these variables. More important, they found that a composite measure called "resolvable lines over target," which incorporated both SNR and number of scan lines, was a good performance predictor. A composite measure of this sort is more meaningful than simply a measure of scan lines across the target, because it incorporates other physical display characteristics that affect image quality.

Hollanda and Harabedian (1969) present results from a series of experiments investigating performance with line-scanned images produced from photographs of military vehicles. They present a series of three-dimensional plots of identification accuracy as a function of the number of line scans per vehicle and the signal-to-noise ratio. Graphs are presented for two kinds of vehicles (tanks or support vehicles) and two kinds of noise (Gaussian and independent of the signal level; or Poisson and signal-dependent). One of these graphs is reproduced in Figure 4-11. Previous work from their laboratory had shown that with noiseless imagery, satisfactory performance (80% correct identification) was obtained with approximately 20 scans per vehicle. However, they concluded that at moderate noise levels (SNR $\geq$ 10), at least 30 to 40 scan lines per vehicle are required

for satisfactory performance. This conclusion holds for both types of noise they studied. It should be noted that the type of task required of the subject was quite difficult, involving matching detailed pictures of scale-model vehicles with the models themselves.

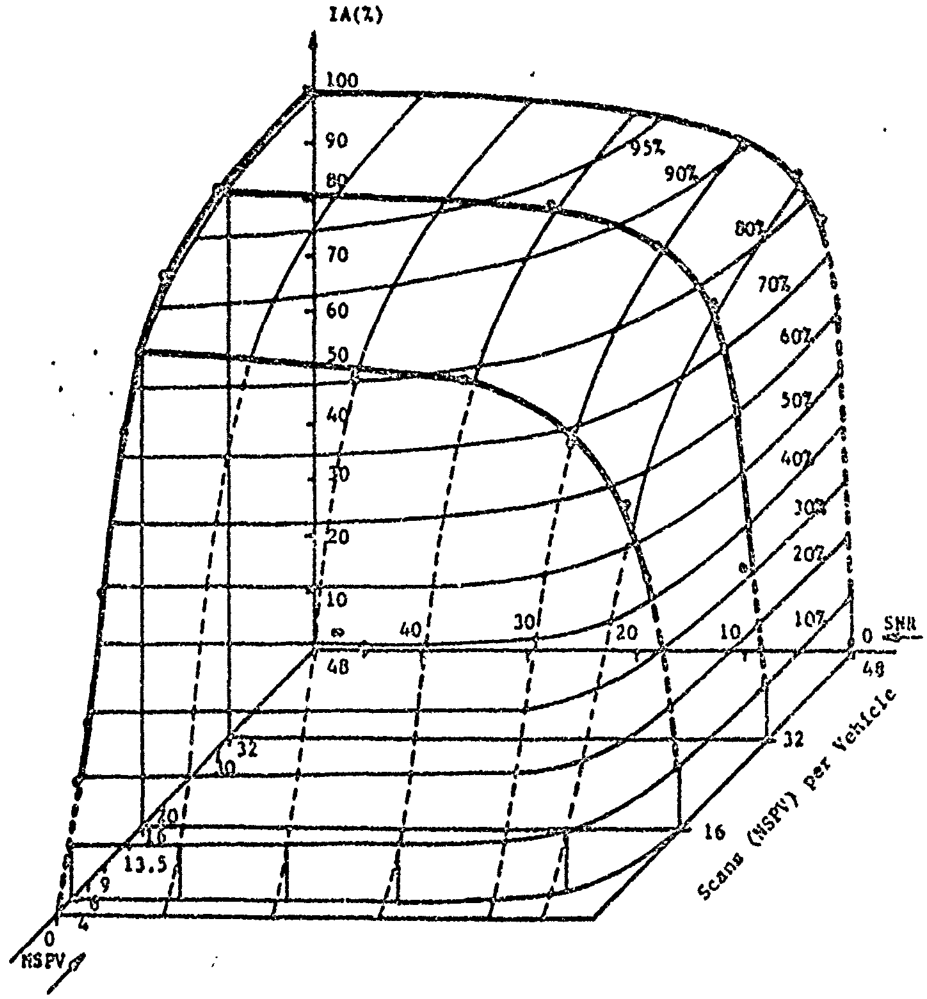


Figure 4-11. The Response Surface for Support Vehicle. The identification accuracy (IA) is shown as a function of the number of scans per vehicle (NSPV) and the signal-to-noise ratio (additive, gaussian noise). (From Hollanda and Harabedian, 1969.)

It should be clear from this review that there is quite a bit of diversity in the results of line-scan experiments. This is understandable when it is remembered that experiments from each laboratory used a particular imaging system that was different, to some extent, from that used in any other laboratory. Thus, even if all procedural details of the experiments had been the same, and the same number of lines had been placed across the same targets, there would have been differences in quality of the images produced. In addition to the physical differences between imaging systems, it must also be remembered that the line number criterion will vary as a function of such parameters as the level of discrimination required, the type of target, the type of mission, the level of briefing, the type of target acquisition task, and so on. So at best these experiments can be used to provide general guidelines. As a summary recommendation, Self (1971) suggests that 15-20 scan lines across the target are necessary for identifying unbriefed targets. If the system is moderately noisy, this estimate may go to 30 or more lines. A recent (1972) working paper from the Target Acquisition Working Group presented a summary of estimated line numbers for three different mission conditions and three levels of target discrimination. This summary is presented in Table 4-III. Again, it should be cautioned that these numbers are meant to be guidelines (in fact, the relationships between the numbers may be more informative than their absolute values.) This is because the raster line number in itself says little about the true "resolution" of the system -- meaning its ability to convey information about the objects it views. For a system with especially good or bad "resolution," these numbers might be considerably in error.

TABLE 4-III

Estimated Required Number of Scan Lines Across Target as a Function of Mission and Level of Discrimination (from TAWG Working Paper, 9 August 1972)

Condition	Required Number of Scan Lines		
	Detection	Recognition	Identification
1. Accurate mission briefing Target location known No friendlies in area Few clutter objects Accurate aircraft NAV systems	4	6	8
2. Accurate mission briefing Target location not precisely known Clutter objects present	6	10	16
3. Reconnaissance/surveillance Friendlies in area Target location not precisely known Clutter objects present	6	15	20

Once an estimate of required scan lines has been obtained, the formulas and figures in Section 4.2.1 may be used to determine total raster line number for various FOV's, slant ranges, and target sizes. Although these figures were previously discussed in terms of Johnson's resolution line criteria, they are equally applicable to the calculation of raster line number.

It is hoped that future work in this area will proceed along the lines of those studies which investigated scan line number in conjunction with one or more other variables (e.g., target angular size, signal-to-noise ratio). Multi-variable studies of this type are helpful because they provide designers with information on the tradeoffs involved. This section has provided some representative data of this type; it is hoped that much more will become available in the future.

Raster Line Density and Sharpness

The studies reviewed above were concerned with how the number of raster lines across the target affected perception of the target. The desired goal of this research is, of course, to be able to specify the required total raster line number of the system, once other parameters are determined (e.g., FOV, required slant range, target size). It was pointed out that equations (4.1) and (4.2) can be used for that purpose.

Some researchers, rather than analyzing the requirements for a particular target, have varied the total raster line number and studied performance on some task. One of the most comprehensive of such studies was performed by Humes and Bauerschmidt (1968). They found that target recognition performance while observing a moving scene varied directly with the system line number. When the camera was pointed in a forward and downward direction, the percent of correct recognitions and recognition slant ranges increased as the line number increased from 729 to 1029 lines. The improvement with the higher line number was especially great at longer slant ranges, and with smaller targets. It is not known whether further improvement would have resulted from a still greater line density.

As a result of a number of considerations, Carel (1965b) has recommended the use of a 1000-line raster in airborne displays. He states that this is a reasonable compromise between what is currently available and what is really needed. Semple et al (1971) state that Carel's recommendation would: "...help to compensate for image degradation due to the multitude of parameters affecting resolution. Assuming similar raster size and 80 blanked lines (for retracing) this figure amounts to about 115 lines per inch or almost twice the number of lines found in the average 1967 display. On the assumption that the eye's resolving power is limited to about one minute of arc, Carel's display recommendation would approach the limits of the eye. One minute of arc is equivalent to 120 lines/inch (47/cm) viewed at 28 inches (71cm).

Other reviewers, however, (e.g., Ketchel and Jenney, 1968) do not agree that such a high line number should be recommended. They argue that further research on the relationship between line number and human performance is needed before such a recommendation should be made.

Clearly, it is not desirable to provide greater raster line density than is really needed. If the eye cannot use all the information that is presented, then the design is wasteful, having squandered bandwidth, power, etc. Furthermore, sometimes providing more raster line density can actually result in a decrease in observer performance. For example, if the line number is raised by increasing the bandwidth, it must be remembered that noise increases as the square root of bandwidth. If the SNR is fairly low to begin with, the further decrease in SNR may offset any potential increase due to the greater number of scan lines (cf. Biberman, 1973). On the other hand, if bandwidth is held constant then the horizontal resolution will drop, which again may result in an overall decrease in performance.

The sharpness or clarity of the individual raster line can have a marked effect on the visibility of the picture presented. Contrary to what is believed by the layman, a sharp, well-focused scan line does not make for a sharp, clear picture. Biberman (1972) has taken considerable effort to stress this point, and notes that even today many designers seem unconcerned with the issue of raster line visibility. He presents pictures of line-scanned images in which he demonstrates that by defocusing a sharp image the picture becomes more readable. This happens because the high-frequency raster becomes blurry faster than the lower-frequency detail in the picture. He has these comments about raster line visibility: "As the new displays come into the development cycle it is most important that the line structure be minimized in order to maximize the usefulness of the new displays to the human viewer...Well-designed displays should never have a raster pattern that is visible from a normal viewing distance. The displays we get will continue to be poor as long as we don't understand these facts and are willing to buy television sets that mutilate imagery with sharp black and white lines. One must be sure that the set has fuzzy lines that are almost invisible but a sharp picture, NOT vice versa."

Thus, the information that is presented along a raster line, and across successive lines, must not be degraded by the presence of high-frequency interference produced by the lines themselves. If the lines are clearly visible, the observer must back up in order to get as much information from the display as he can. But if the lines were less visible, he could then move closer to the display, and see more of the detail that was really there all along, but was being masked.

That observers do in fact behave this way was confirmed by Thompson (1957), who studied how close to a display people prefer to sit, when raster structure is present in varying degrees. Subjects were asked to view a static image at a close distance, and then to move back until they felt comfortable viewing the picture. When viewing a conventional raster display subjects chose a distance at which each raster line subtended approximately 1 minute of arc at the eye. When the raster structure was then made less visible, subjects sat substantially closer to the display. This study is discussed further in the section on spot wobble (Section 4.2.17).

4.2.4 Display Size/Viewing Distance

This section presents experimental results and recommendations concerning two combined factors: size of the display, and the distance at which it is viewed. These two variables should be considered together since they combine to determine the angular size of the display as seen by the observer.

It should be noted that this discussion concerns only the angular size of the display -- not that of the target. The effects of target size on acquisition performance have been covered in Chapter 3.

Display size/viewing distance is a topic that is frequently discussed but less often investigated experimentally. This is perhaps because the considerations are more logical than empirical, and derive from a few basic facts about vision. Of the experimental results available, most show display angular size to be a relatively unimportant variable, over the range of values studied. This is true, provided the resolution of the sensor/display system is not wasted, due to the resolution of the eye. In those studies where no performance differences were found as a function of display angular size, the reasons were probably one of the following: (a) the detail that was present in the display could be discriminated at the smallest visual angles studied; or (b) the extra detail available at larger visual angles was not critical for performing the task; or (c) as visual angle increased and more detail became available, this detail was masked by the raster structure, which also became more visible.

For example, Parkes (1972) reviews several studies which showed that, although a slight drop in performance occurred as display visual angle decreased, the effects were not significant. Parkes conducted a study in which viewing distance changed while display size stayed the same. Subjects were required to locate targets on black and white aerial photographs; no raster lines were present. As viewing angle decreased from 21° X 15-3/4° to 9° X 7°, there was a slight but nonsignificant drop in performance.

An experiment by Swinney (1968) employed 3", 6", and 9" (7.6, 15 and 23 cm) displays viewed at 24" (61 cm). Detection of personnel targets was not affected by variations in angular size of the display. However, vehicular targets were detected somewhat less frequently at the smallest angular size than at other sizes.

Bruns et al (1970) found essentially no differences between 3 display sizes and 5 display angular heights ranging from 6° to 18°, where the task involved identifying television-displayed targets whose location was known. In a later study, Bruns et al (1972) measured target detection performance as well as identification performance, and again found that the display visual angles studied had no effect on any of their performance measures.

A number of additional experiments with similar results could be cited. However, the above summary should make it clear that, in general,

researchers have found display angular size to be of relatively little importance to target acquisition performance. However, some reviewers believe that considerable thought should go into the choice of display size and viewing distance, and that these variables may have been neglected in the past. The following paragraphs discuss some of the factors that should be considered.

The choice of display size/viewing distance should be based on such considerations as the resolution of the eye, the smallest amount of detail that is present in the display, the visibility of the raster line structure, and physical space constraints. Space constraints are often a serious problem, and frequently result in a display that is either too small or too far away from the observer's eye to be adequate for the task for which it was designed. Biberman et al (1971) state that "more of the early airborne systems were deficient because of inadequate display size than for almost any other reason.....There are some fine systems under design or in production that overmatch the human eye by factors of 4 to 10. That is, the detail displayed by the sensor is of good quality, but a magnifying glass of 4 to 10 power is required to enable an airborne observer to see it." Thus, since space limitations cannot be ignored, it is important to consider these limitations when determining what kind of resolution the system will have. In this fashion, systems will not be designed that present far more detail than the observer can use.

As discussed in the section on raster line effects, when the high-frequency raster pattern is visible to the observer, much of the information present in the display can be effectively masked. Thus it is important that the display angular size not be so large as to make the scan lines easily visible. One minute of arc is commonly accepted as the resolution of the eye (although it can be much less), and the results of Thompson's (1957) experiment showed that subjects preferred to sit where the raster lines subtended approximately 1 minute of arc. Thus, although some studies (e.g., Erickson and Hemingway, 1970a) have shown that some people can see raster lines when they are smaller than this, the 1 minute figure seems a good guideline for maximum raster line size. Figure 4-12 presents the maximum permissible display height as a function of the number of active scan lines, for a variety of viewing distances. It should be stressed that this figure presents guidelines based on the assumption that a scan line subtense of 1 minute is the point at which the lines begin to interfere with perception. If systems (using spot wobble or some other technique) are designed with less raster line visibility, these limitations can be relaxed.

The effects of vibration on performance should also be considered by the designer. Biberman (1973) has pointed out the importance of this factor. In high-performance aircraft, especially when flying at low altitudes, vibration and buffeting can be substantial. The display and the head of the observer will seldom if ever vibrate in unison, so there is an almost continuous relative motion between the two. The resulting angular displacements are greatest at short viewing distances. Thus, whenever it is possible to do so, increasing the viewing distance and the display size, while keeping the display angular size constant, will reduce the harmful effects of vibration. (See Chapter five for a discussion of vibration effects.)

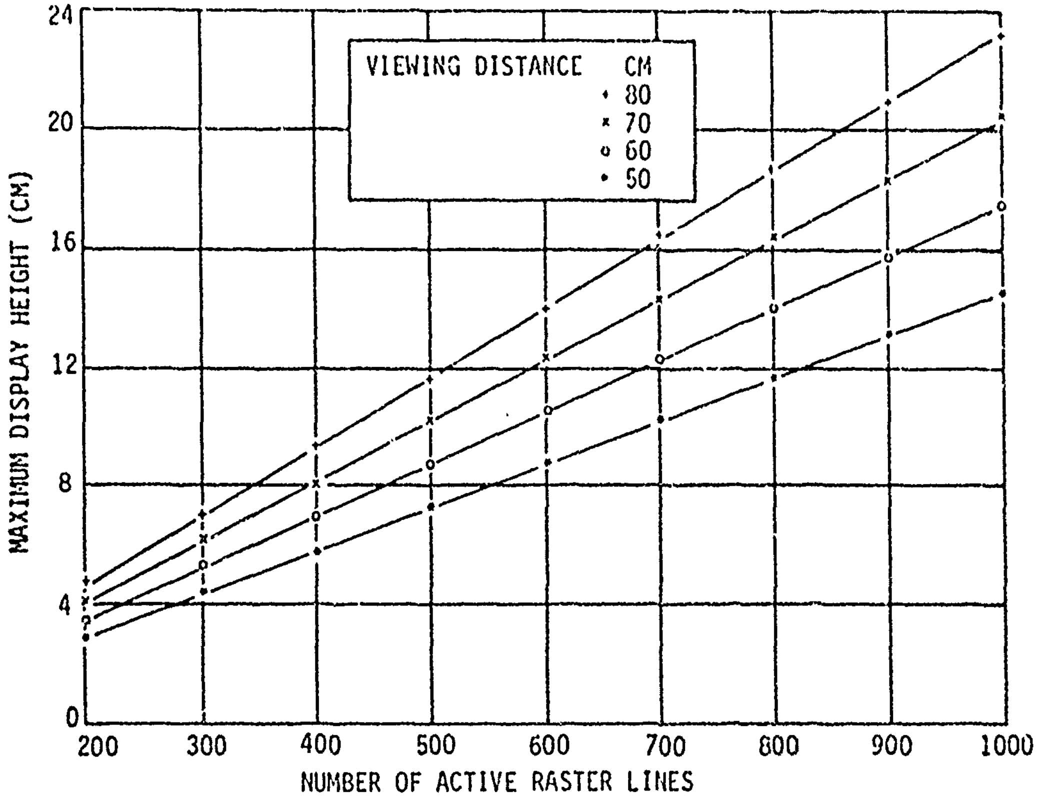


Figure 4-12. Maximum Display Height as a Function of Raster Line Density, for Several Viewing Distances. Assumes raster lines should subtend no more than 1 minute of arc at the eye.

Although it is not appropriate in this chapter to provide a lengthy discussion of the effects of target size, the work of researchers such as Steedman and Baker (1960) should be noted. The results of several studies exploring search performance as a function of target size have shown that both search speed and accuracy of target recognition are relatively poor when the target size is less than approximately 12 - 20 minutes of arc. This finding is valid across a range of resolution values. Here then is another factor to be considered when determining display angular size. Some sample calculations should be made of the displayed sizes of various targets when seen by the sensor at representative slant ranges. If displayed angular sizes are below 12 - 20 minutes of arc and hence are too small for rapid target detection, serious thought will have to be given to increasing display size or decreasing the sensor field of view.

Another consideration when determining display angular size is the optimal search efficiency that can be obtained. Enoch (1960) has investigated search efficiency on displays ranging from 3° to 51°18', when subjects were searching for an abstract target (a Landolt C). He found

that search efficiency dropped when display angular size was less than 9°, because a large percentage of the observer's eye fixations fell outside the display area. Furthermore, at display angles greater than 9° efficiency also decreased, because observers tended to concentrate their fixations in the center of the display. He therefore recommended 9° as the optimal display angle for highest search efficiency. In Figure 4-12, size/viewing distance combinations that result in a 9° display angular size may be found at a raster line number of 540.

4.2.5 Display Luminance and Ambient Illumination

There are several factors that need to be considered when selecting optimal picture luminance (brightness) levels. One of the most important is a consideration of the other visual tasks the observer is required to perform in addition to monitoring the display. It is important that the display luminance, to whatever extent practical, be consistent with the luminance levels encountered in these other visual tasks. If a mission is being flown at night or at dusk, and the observer must remain in a relatively dark-adapted state, the average display luminance should be kept at a relatively low level. It should not, however, fall below the range of sensitivity of the eye's cone receptors. As discussed in Chapter 2, visual acuity is greatest when these receptors are operating. Therefore, display luminances below approximately 1.0 footlambert (fL) or 3.426 candela/m^2 (cd/m^2) should not be permitted when perception of fine detail is important (cf. Table 2-1).

Conversely, if a daylight mission is being flown, in which the cockpit illumination is high and the observer is required to look out the window at bright sky and terrain, then display brightness must be considerably higher. Otherwise, valuable time might be lost while the observer adapts to the luminance level of the display.

In general, if dark-adaptation is not a problem, relatively high display luminance levels are advisable. As discussed in Chapter 2, laboratory experiments have shown that as brightness increases, smaller objects and objects of lower contrast can be detected with the same level of confidence. Identification studies have confirmed this fact. For example, the legibility of letters displayed on TV has been shown to increase as display luminance increases from 1 to 40 fL (3.426 to 137 cd/m^2) with the greatest increase occurring between 1 and 20 fL (3.426 to 68.52 cd/m^2) (Shurtleff, 1967). A motion picture film simulation study by Mardon (1969) (reported by Parkes, 1972) showed that target detection ranges increased as display luminance increased from 0.19 to 4.15 fL (0.65 to 14.2 m^2).

Visual performance during daylight operations can be degraded seriously if stray light (especially direct or reflected sunlight) falls onto the display face. Ambient illumination incident on the display drastically reduces the obtainable display contrast ratio (see Section 4.2.6). Bruns (1971) states that most standard CRT phosphors reflect about 70% of the light striking the display face. Thus, in the case of bright skylight, approximately 2000 footcandles (21,528m cd) falling on the display, if

maximum display brightness were 500 fL (1713m cd), the maximum obtainable display contract ratio would be approximately 1.4/1 (1400+500/1400). The use of filters in front of the display can increase this ratio, but they may introduce other problems. For example, overall display luminance will be reduced, and reflections may be picked up from objects in the cockpit. A discussion of some of the available filters is provided by Bruns (1971) and Bruns and Miller (1969). For a good discussion of the pros and cons of several types of filters, along with other techniques for maintaining sufficient display contrast in the presence of high ambient illumination, an excellent report is that of Ketchel and Jenney (1968). A variety of high-contrast CRT's have also been developed, which combine filters with special phosphors, in order to permit their use even under conditions of direct sunlight at high altitudes, 10,000 to 15,000 footcandles (107,640 to 161,460m cd). For an experimental evaluation of some of these CRT's, see Knowles and Wulfek (1972).

Fozard (1962) has discussed the consequences of ambient light falling on the display. He noted that when light falls on the picture the typical response of the observer is to adjust gamma to a value greater than one, so that displayed contrast is greater than the contrast in the original scene. Whereas some adjustment of gamma would be necessary to bring target/background contrast up to what it would have been without the ambient illumination, Fozard found that this adjustment was generally excessive. The result was that shades of grey in the total image were lost, hence detail rendition decreased. The best ways to counter this problem would seem to be to provide shading and filters wherever possible to prevent ambient light from reaching the display, and to instruct the operators as to the effects of setting gamma too high.

Another problem that must be discussed in connection with ambient illumination is the problem of light entering the eye from the area surrounding the display (commonly called glare). Glare, which is discussed in Chapter 2 (Section 2.4.4), may be thought of as producing a "veiling luminance" through which the observer must see. Glare can be reduced by providing a hood for the observer, or by similarly reducing the amount of outside light striking the retina. One approach suggested by Fozard (1962) is, when the observer has no outside visual tasks to perform, to line the aircraft canopy with polarized material and have the observer wear cross-polarized glasses.

As Farkes (1972) points out, it is typically recommended that display luminance be sufficiently high that the luminance of the surroundings is at least 10% less than that of the display. With such an arrangement a display contrast ratio of 8:1 would be sufficient to discriminate seven shades of gray for an image subtending 8 minutes of arc (Slocum et al, 1967). If, however, surround luminance is substantially higher than the display (by an order of magnitude or more), then a much greater display contrast ratio (perhaps 30:1) is required for the same discrimination level. A study by Clare (1970) showed that target acquisition via TV was not affected when surround/display luminance ratios were varied from 15/48 mL to 1.5/48 mL to 1.5/4.5 mL (47.7 to 152.8 cd/m^2 to 4.77/152.8 cd/m^2 to 4.77/14.3 cd/m^2) but that a ratio of 15/4.5 mL (47.7 to 14.3 cd/m^2) was too high for data to be obtained.

In many situations it is simply not possible to avoid using a display in which the background luminance is considerably less than that of the area surrounding the display. In such cases, it is desirable to know to what extent performance will be affected. Ireland et al (1967) have conducted a careful study of visual discrimination (using abstract stimuli) for a variety of surround-to-background luminance ratios ranging from 0:1 to 100:1. The results of their study are of practical benefit to designers who wish to calculate threshold contrast levels, and who wish to know the extent to which contrast should be increased when surround brightness is greater than the brightness of the background against which the target is viewed. They found that the threshold contrast for detecting the gap in a ring target increased as the surround-to-background ratio increased, when the surround was brighter than the background. When the surround was darker than the background, the thresholds did not vary significantly. They present equations for applying these data to conditions of interest, and correction factors for extending the results to real-world situations. These equations and corrections are presented below. They are based on the assumption that the smallest target detail to be perceived is approximately 2 minutes of arc, and that the target is at least 2.5° away from the bright surround.

If it is assumed that a surround which is brighter than the displayed scene background is unavoidable, and if some estimate of these levels can be made, the following formula will estimate the increase in required target/background contrast over that required when surround luminance is equal to background luminance:

$$C'' = C_{ref}\ (0.95 + 0.05\ \frac{LS}{LB}), \tag{4.4}$$

where,

C'' = Conservative estimate of threshold contrast for a given ratio, $LS/LB > 1$

C_{ref} = Threshold contrast when $LS/LB = 1$

LS = Luminance of the area surrounding the display

LB = Luminance of the background against which a target is seen.

If the value of C_{ref} is not known or assumed, it may be estimated from the following equation:

$$\log C_{ref} = -0.368 - 0.253(\log LB), \tag{4.5}$$

where all terms are as defined in equation (4.4). Equation (4.5) applies to the calculation of the target/background contrast needed for a .50 probability of discrimination, when the target is brighter than its background, and subtends 2 minutes of arc at the eye. Ireland et al state that it is valid for values of LB from 0.1 mL to 200 mL (0.318 to 636.6 cd/m^2), and that extrapolation beyond this value will underestimate C_{ref}.

To make these equations of greater practical value, two correction factors are recommended. First, to obtain the contrast required for .99 probability of discrimination, Ireland et al calculate that equation (4.4) should be multiplied by a factor of 4.2. Second, to extend the results from a laboratory setting to a more realistic environment, a minimum multiplication factor of 6.25 is suggested.

Figure 4-13 presents some representative results of the above series of calculations. The figure presents the estimated contrast thresholds required for 0.99 probability of detection in a practical visual task involving critical details no smaller than 2 minutes of arc. These thresholds are presented as a function of background luminance (LB), for values of LS/LB ranging from 1 to 100.

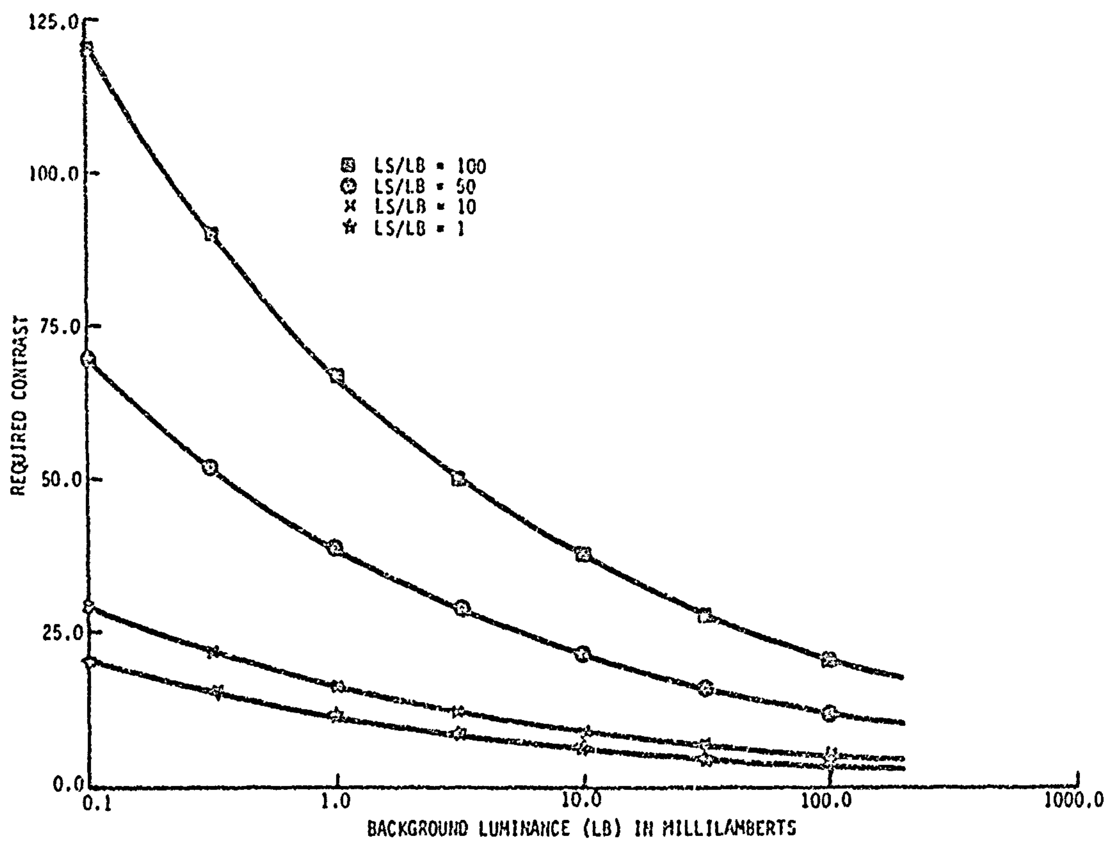


Figure 4-13. Estimated Contrast Required for Detection Probability of .99 in a Practical Visual Task Involving No Smaller Than 2 Minutes of Arc. Presented for various ratios of surround luminance (LS) to background luminance (LB). See Equations (4.4) and (4.5).

As for recommending maximum display luminances that should be provided in airborne visual displays, Ketchel and Jenney (1968) state that sufficient research has not yet been done to permit firm recommendations to be made for different situations. They do, however, state their belief that 500 fL (1591.5 cd/m2) should be sufficient for ordinary head-down display applications. If this proves inadequate in a particular cockpit environment, they argue against the "brute force" approach of providing an even greater luminance level, which is costly in terms of voltage requirements, reliability, and other factors. Rather than maintaining sufficient contrast by increasing output luminance, they argue that efforts should be directed toward developing more efficient contrast enhancement techniques. They provide a listing and discussion of several such techniques which hold promise and which clearly should be evaluated in an extensive research program of between-display comparisons.

Finally, it should be added that most of the small amount of research that has been done has been concerned with display legibility or with the discrimination of abstract targets. Effort needs to be extended in the direction of realistic target acquisition problems.

4.2.6 Display Contrast Ratio, Gamma, Shades of Grey

These three topics are combined in the present report because they are interrelated and difficult to separate. For example, the gamma of a system, which may be loosely defined as the slope of the function relating log input luminance to log output luminance, can be considered as the contrast transfer function, as it determines whether the display contrast ratio is greater than (gamma > 1), equal to (gamma = 1), or less than (gamma < 1) the input contrast ratio. The studies reported in this section will, for convenience, be grouped according to the authors' terminology. But, because of the way these topics are interconnected, some overlap is inevitable. For example, what one author might describe as a change in gamma, another author could call a variation in the number of shades of grey.

Display contrast ratio is not identical to target/background contrast as defined in Chapter 2 (Section 2.3.1). Rather, it is defined as the ratio of the brightest to the darkest portion of the displayed scene. Very little research has dealt with display contrast ratio; a study at Autonetics (Humes and Bauerschmidt, 1968) is the most operationally relevant experiment on this topic. Under the conditions of their experiment, which involved searching for targets in a dynamic scene, they found the percentage of targets correctly recognized to be greatest at a "medium" display contrast ratio (60), compared to ratios of 1.25 and 600. Fairfield (1970) also quotes a Russian report which states that a TV picture with a contrast of 30 may be considered "good"; a contrast of 100 is "excellent"; and above 100 is of no value in improving image quality.

The factor of ambient illumination must also be taken into account when specifying the minimum acceptable contrast ratio. It is recommended that the surround luminance be at least 10% below that of the display. If

this condition cannot be met (which is often the case in a cockpit environment), a greater display contrast ratio would be required to discriminate a given number of shades of gray. For a discussion of contrast requirements as a function of ambient illumination, see Section 4.2.5.

Only a few studies have been directly concerned with the effects of different system gammas on target acquisition. One experiment that did investigate this variable was reported by Fowler, Freitag, Jones and King (1971). Three values of gamma were employed: 0.55, 1.0, and 2.2. The effect of the low gamma is to compress the bright end of the scale of scene luminances, relative to the scale at the dark end of the continuum. The effect of the high gamma is just the opposite. The result is that, although an increase in gamma produces an increase in target/background contrast, the amount of contrast change depends on the initial contrast level. For example, if a target is brighter than its background, a change in gamma results in a greater contrast change for high contrast targets than for low contrast targets, provided the dynamic range of the system is not exceeded. The result of the Fowler et al study was that higher gamma generally resulted in better detection and recognition performance. This result can be attributed to the effect of contrast; when contrast was held constant, the differences between the gamma levels were unclear. A relatively narrow range of target and background luminances was explored in this study, and the results must be considered tentative.

Another experimental study of gamma, using a photographic rather than television display, was done by Blackwell et al (1961). Subjects performed a target detection task while viewing vertical aerial photographs of a terrain model. Four values of gamma were studied: 1.0, 1.8, 3.1, and 4.0. As gamma increased, so did the target/background contrast of all targets displayed. The results showed that target detection probability increased substantially as gamma increased. This effect was most pronounced when the detection probability for a gamma of 1.0 was relatively low. When this probability was high, the percentage improvement obviously could not have been great, since performance cannot be greater than 100%. There is some evidence that, if detection probability is very high when gamma ≈ 1.0, increasing the gamma to 4.0 results in a slight drop in performance.

The conclusion to be drawn from relatively sparse evidence is that, in the absence of firm information about the target and background luminances to be encountered, it is probably best to stay with gamma of about 1.0. This is essentially a compromise between contrast and dynamic range. On the other hand, if the mission involves searching a desert region for light-colored targets, then it may make sense to expand differentially the bright end of the scale by increasing gamma -- even though dynamic range at the low end is sacrificed. More research should be done to determine the advisability of providing the observer with a gamma control, as well as to study a wider range of gamma values, target/background conditions, levels of clutter, and so forth. Such research could be fruitful, especially when considering various sensing systems (e.g., spectral signature) that often result in pictures representing gammas substantially different from 1.0.

The number of shades of gray provided by the system is usually measured electronically rather than psychophysically. One gray step is generally defined as a 3 db increment in signal level (Hairfield, 1970); this corresponds to a ratio of $(2)^{\frac{1}{2}}$: 1 between adjacent luminance levels. Hairfield (1970) points out that, considering the range of luminances to which the light-adapted eye can respond, the theoretical maximum number of shades of gray a system should provide is about 14. The weight of experimental evidence, however, suggests that from seven to ten shades is sufficient.

Slocum et al (1967) suggest that a minimum of seven shades should be provided when a complex scene is being searched. Johnston (1968) corroborates seven as a minimum number, in a study where target recognition performance was studied as a function of either five, seven, or nine shades of gray. She found that recognition times were significantly longer (by approximately 50%) with five shades of gray, compared to seven or nine shades, at relatively long slant ranges (approximately 3.5 and 4.5 kilometers), although the difference disappeared at shorter ranges (1.8 and 2.7 kilometers). Thus at comparatively long ranges, where the apparent target size is small and the scene complexity is high because of the amount of ground area covered, fewer than seven shades of gray is undesirable.

Ketchel and Jenney (1968) argue that approximately 10 shades of gray should probably be provided in order to produce sufficiently realistic TV images for optimal performance. They point out, however, that sufficient research has not yet been performed, and that an easy answer is not forthcoming because of possible interaction effects between shades of gray and the resolution of the system. In part, more shades of gray are required in order to compensate for resolution limitations in some present-day sensors. They suggest that with sufficiently high resolution, the required number of gray shades may be reduced. As Biberman (1973) points out, however, both "resolution" and "shades of gray" are related to the displayed signal-to-noise ratio as a function of spatial frequency; he refers to both concepts as "subjective" manifestations of the signal-to-noise ratio. Modern-day thinking on the subject of image quality relies heavily on the concept of displayed signal-to-noise ratio (see Section 4.3) as a unifying measure which ties together many of the older image quality parameters.

Supporting evidence for the use of not more than 7-10 gray levels comes from a photographic study by Gaven et al (1970). Subjects performed an identification task while viewing pictures that were encoded with from 1 to 7 bits of luminance (2 to 128 gray levels). Performance increased rapidly up to about 3 bits; little if any further improvement was observed from 3 to 7 bits.

Two studies performed by Greening and Wyman (1968 and 1969) investigated shades of gray on high-resolution radar imagery. Radar imagery was produced by an airborne radar system at an altitude of approximately 10.5 kilometers. The stimulus materials were positive transparencies of this imagery; the subjects' task was to recognize targets such as bridges,

factories, barracks, etc. The imagery was produced by employing either 3, 5, or 11 shades of gray. Figure 4-14 illustrates these conditions. As is seen by these transfer curves, another way of describing the differences between conditions is to say that the dynamic range of the scene was varied, with different levels of gamma occurring across that range. The results of the first study showed that target acquisition performance (probability of recognition latency) was positively related to the shades of gray in radar imagery. As gray shades increased from 3 to 5 to 11, recognition probability increased from .56 to .67 to .82, and latency decreased from 11.0 sec to 9.6 sec to 8.6 sec. Thus the amount of improvement from 3 to 5 shades is about equal to the improvement from 5 to 11 shades; therefore, adding a few more shades probably would not have had much additional effect. This is further evidence that there is little reason to incur the costs of providing more than about 10 shades of gray.

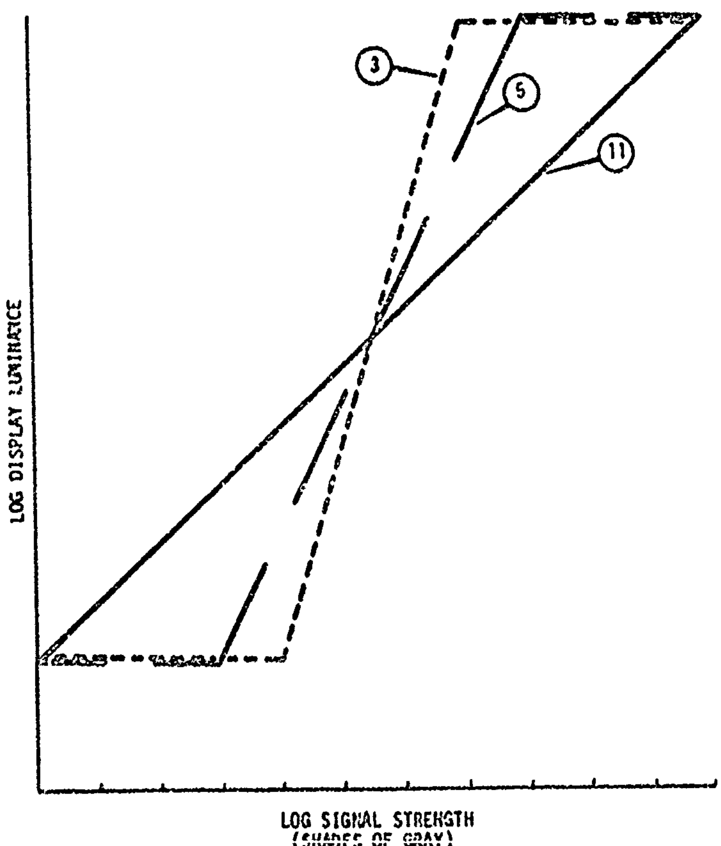


Figure 4-14. Transfer Curves for Three Dynamic Ranges, Representing Either 3, 5, or 11 Shades of Gray (adapted from Greening and Wyman, 1969).

These results were confirmed by Greening and Wyman (1969), who compared the 11 shades of gray condition with the 3 shades of gray, where the latter condition was either as shown in Figure 4-14, or shifted to the right or the left -- thereby enhancing discrimination of either "hard" or "soft" targets, respectively. The results showed that the wide dynamic range condition was superior to the narrow range condition, despite the fact that the narrow range window could be shifted so as to be centered on that part of the scale where a particular target was located. On 21 of the 25 targets, recognition performance with 11 shades of gray was as good as or better than the best of the narrow range conditions for a particular target class. Thus, for radar imagery, under the conditions of these studies, sacrificing shades of gray (dynamic range) for a higher gamma was not justified.

4.2.7 Signal to Noise Ratio

Many studies have demonstrated that perceptual performance becomes degraded as the signal-to-noise ratio (SNR) of a system decreases. In general, the results from a number of studies have shown that performance improves as a function of SNR up to some point (approximately 16-25 db), beyond which further increases in SNR are of little or no importance. This review will briefly discuss a few of those studies that are most pertinent to the problems of target acquisition, and will concentrate on those that indicate the SNR value at which performance seems to level off.

Signal-to-noise ratio is commonly defined as the ratio of the peak-to-peak signal amplitude to the root-mean-square (rms) noise. Peak-to-peak signal amplitude refers to the difference between the maximum and the minimum signal values; rms noise can be considered as the standard deviation of the random fluctuations around a given signal level. For the reader interested in more extensive definitions and descriptions of various measurement techniques used with TV camera tubes, see Biberman and Nudelman (1971, Vol. 2). Signal-to-noise ratio is often expressed in units of decibels (dB), rather than as a simple quotient. In this section the dB form will be used, where

$$\text{SNR (in dB)} = 20 \log_{10} (\text{peak-to-peak signal / rms noise}). \qquad (4.6)$$

Most of the studies investigating SNR for electro-optical displays have employed static imagery viewed through a TV system. For example, Parkes (1972) required subjects to locate targets in oblique terrain photographs. She varied noise level in order to obtain SNR's of 30, 24, 19, and 14 dB. In comparison with a direct-view condition, the two higher SNR's did not result in a significant performance decrement. A sharp drop occurred, however, between the 24 and 19 dB conditions. Thus, under the conditions of this study, an SNR of 24 dB was fully adequate. Parkes also reviews a few additional studies with static imagery, in which the targets were abstract geometric forms.

A study by Williams et al (1965) represents a rare attempt to study SNR under conditions of scene motion, rather than with static displays. In studies involving geographic orientation relative to a predesignated target position, no performance differences were found among SNR's of 15 db, 20 db, and over 50 db. In an identification task, however, involving discrimination between moving circles and hexagons viewed against a cluttered background, performance was significantly degraded under the 15 db condition.

Another dynamic target acquisition study is that of Humes and Bauerschmidt (1968). In this study subjects viewed a television display of aerial reconnaissance films. The SNR levels studied were 1, 7, 16, and 37.6 db. In this study the 16 db condition was the level below which performance deteriorated. This was especially true for percent correct recognition, but also for recognition speed provided the targets were either of low contrast or small. The authors conclude that a TV system designed for use against small tactical targets should be capable of providing an SNR of at least 16 db for undegraded performance.

It should be pointed out that noise seen on a live televised picture is fundamentally different from that seen on a photograph, because it is continuously changing in a random fashion. Dynamic noise is considerably less disruptive than static noise because of the temporal integration properties of the visual system (cf. Chapter 2). Since the eye and brain do not register each fleeting change in brightness, the rapid random fluctuations are averaged out, and the slowly-changing information in the scene is perceived more easily. Thus a target can be discerned more readily than it could be if the noise were "frozen." The detrimental effects of static noise have important implications for the concept of display freeze, discussed in Section 4.2.11. If a particular frame were stored and displayed repeatedly, noise that was generated by the phototransducer would be frozen along with the signal, and would therefore affect the perceptibility of the signal. This fact should be considered when determining the benefits likely to be derived from display freeze.

In addition to the temporal characteristics of the noise, spatial characteristics can also affect the level of performance. In a preliminary study by Hillman (1966) the detection or recognition of small targets was degraded more by noise of high spatial frequency than low frequency noise. In general, from her pilot work, she concluded that noise is most detrimental when its spatial frequency matches that of the objects being searched for.

In summary, this review has presented results from a few representative studies that have shown acquisition performance to be a negatively accelerated increasing function of SNR. The particular value of SNR, above which little further benefit is obtained, depends on a variety of experimental details. However, there is quite a bit of consistency between studies. Hairfield (1970), after reviewing a number of classified as well as unclassified studies, concludes that this critical SNR level lies between 16 and 25 db.

The topic of SNR will be discussed further in Section 4.3, in connection with a summary measure of image quality. It will be shown that the SNR, when modified to include such factors as the image size and the temporal integration properties of the eye, can be used to predict simple target acquisition performance in a variety of situations.

4.2.8 Frame Rate

In considering the frame rate or information update rate to be employed, two basic problems must be kept in mind: the likelihood that a particular frame rate will result in flicker of the displayed picture, and the likelihood that an unacceptable amount of target blur or smear will occur, making detection or identification difficult.

With regard to the first problem, it should be noted that, at the very least, the presence of flicker can be extremely annoying. Furthermore, if continued for a long enough period of time, it can degrade performance because of its fatiguing effects and its effects on motivation. If the frame rate is slow enough to produce flicker, the problem could be counteracted by increasing the interlacing beyond the customary 2:1 (see Section 4.2.9), or by employing storage circuitry that enables the same scene to be presented on successive frames. If such changes are unacceptable for design reasons or because of other considerations, then the field rate (equal to twice the frame rate for a 2:1 interlace) should not fall below the critical flicker frequency (CFF) for the display luminances encountered. It is difficult to predict CFF from laboratory data using square-wave pulses because of the nature of the raster-scan process, the characteristics of the particular phosphor used, etc. The general relationship, as presented in Chapter 2 (Section 2.4.6), is that flicker will be perceived at higher repetition rates as the average luminance level increases. The likelihood of flicker can thus be reduced by reducing display luminance. A second procedure is to utilize a longer-decay phosphor. This approach would be effective only if there were relatively little image motion, for image motion produces smear with a slow phosphor. Carel (1965) presents curves, which are adapted from earlier work by Schade, that show CFF for a variety of phosphors and viewing distance/screen diameter ratios (p). The determination of p is important because CFF is generally higher in the periphery of the visual field than in the fovea; thus, CFF increases as p decreases. As a general guide, a frame rate of 30/second (2:1 interlacing) will not produce flicker if the average display luminance is approximately 10-30 fL (34.3-103 cd/m^2), and the highlight luminances (comprising a small portion of the total display) do not exceed 150 fL (514 cd/m^2) (Carel, 1965; Pozard, 1962; Schade, 1964).

Concerning the loss of visual information due to sampling a moving scene at a slow frame rate, relatively little experimental evidence is available. For a review of a few classified simulation studies involving this variable, see Hairfield (1970), Snyder et al (1967), and Hillman (1967). As is true with other parameters discussed in this chapter, simple answers are not available, and the designer must consider carefully how the system

is intended to be used, before making decisions about the tradeoffs involved. Obviously with a relatively high rate of target motion across the screen, image blur could be a serious problem, and a relatively high information update rate would be desirable. Hoffman and Greening (1967) have shown, for example, that if the blur vector exceeds twice the displayed size of the target's "critical" detail, then target acquisition performance is significantly reduced. On the other hand, if sensitivity and power requirements are paramount, it may be necessary to sacrifice frame rate in order to reduce bandwidth and improve signal/noise ratio. One way to reduce the problem of blur when the frame rate is too slow is to shutter the sensor so that it operates for only a fraction of the frame interval (see Section 4.2.10).

As a general statement, it seems advisable to stay with a frame rate of 30 frames/second, unless there are compelling design reasons suggesting a lower rate. In this case, it may be necessary to conduct simulation studies to determine whether detection/identification performance is acceptable under representative operational conditions.

4.2.9 Interlacing

Interlacing is a technique for eliminating display flicker without increasing the data rate, thus conserving bandwidth. TV systems normally employ an information update rate of 30 frames per second. At this frame rate, flicker would be noticeable at typical display luminance levels (cf. Section 2.4.6 and Section 4.2.8). In order for the frame rate to be increased, the scanning spot would have to move across the display at a faster rate, and bandwidth would therefore need to be increased in order to maintain the same horizontal resolution.

In order to maintain frame rate at 30 frames/second and still avoid flicker, the standard procedure is to cause the CRT beam to write every other line, then start at the beginning and fill in the "spaces." This technique is called 2:1 interlacing, and results in a field rate of 60/second, while the information update rate is still only 30/second. Each individual line is still flashing 30 times per second, but at normal viewing distances flicker is imperceptible because the resolution of the eye is sufficiently low at such a high spatial frequency.

An interlace ratio of 2:1 is standard, but in some applications it could be desirable to use a higher ratio. For example, if designated for use in a high ambient illumination environment, the display luminance might be high enough to cause flicker at a rate of 60 fields per second. By using a 3:1 interlace a 90/second field rate would be obtained. As another example, if the scene is changing slowly so that the information update rate of 30/second is not needed, it might be desirable to employ a lower frame rate. By so doing, bandwidth could be reduced, or resolution improved. At 20 frames per second a 3:1 interlace would again bring the field rate to 60/second.

The effect of changing the interlace ratio has not been studied experimentally. In ordinary applications there would be no advantage to increasing the interlace ratio unless frame rates were simultaneously reduced. Research should be done to determine the extent to which such a

change would affect target acquisition performance, for a variety of image rates of motion.

4.2.10 Image Frame Integration Time

One way to reduce image blur caused by high angular rates of motion is to decrease the amount of time during which the sensor collects information, before the information is transferred to the display. This may be done by increasing the frame rate, so that radiant energy is integrated over, say, 1/60 second instead of 1/30 second. However, this solution is costly in that bandwidth would have to be doubled in order for resolution to remain the same. Another procedure is to maintain the same frame rate, but shutter the sensor so that energy is integrated over only a fraction of the frame interval. This procedure is feasible only if the scene radiance level is high enough so that the S/N ratio can remain at an acceptable level.

Experimental investigation of this shuttering technique was conducted by Humes and Bauerschmidt (1968). With a frame rate of 30/second, they studied integration times of 1/60, 1/150, and 1/300 second. Under nadir viewing conditions (camera pointing almost straight down, resulting in highest ground angular rates) target recognition probability was slightly but significantly higher at 1/150 or 1/300 than at 1/60 second. In addition, recognition latency was faster for the 1/300 second condition. With an oblique viewing mode, however, performance was generally unaffected. Similar increases in performance by reducing blur through shorter exposure times have been reported by Hoffman and Greening (1967).

This technique is a relatively simple way of decreasing blur when target angular rates are excessive, and should be given further study.

4.2.11 Display Freeze

In many situations target acquisition performance may be limited by the effects of target motion across the display. For example, at relatively high V/H (velocity/height) ratios, coupled with a small field of view, a substantial proportion of targets may leave the display before the observer has had time to identify them. Or their angular rates may be too great for them to be identified accurately, especially with image smear. A logical solution is to provide the capability of freezing the image at some point, to permit the observer to make a more thorough search of the scene or a more detailed inspection of the target.

Several freeze modes are possible. Freeze may be initiated by the observer, or it may be automatic, based on navigational information. It may be for a fixed duration, or until the operator terminates it. It may also be continuous, consisting of a series of stopped frames of limited duration. Some of these parameters were investigated in two studies performed by Rusis, Snyder, and Greening, (1965a) and Rusis, Snyder, Greening, and Rawlings (1965b), which represent experiments pertinent to the air-to-

ground search problem. In these experiments, subjects were required to search for and recognize tactical targets while watching a TV display of a dynamic scene.

The results of both studies show that display freeze can be very helpful. In the first experiment, recognition performance was improved in the observer-initiated freeze mode, in comparison to no freeze, at slant ranges beyond about 0.4 km. As the duration of the freeze increased from 1 to 5 seconds, performance worsened. An automatically-initiated display freeze, such as could be provided by a computer tied in to an accurate navigation system, was superior to observer-initiated freeze. A continuous freeze condition (every 3 seconds) was inferior to all other freeze modes. In the second study, where slant ranges were measured with more precision, observer-initiated freeze was again found superior to a no-freeze condition in terms of recognition probabilities, but average recognition and designation slant ranges were longer without freeze. Designation accuracy (placing a reticle over the target) was greater with a frozen display.

These experiments indicate that display freeze can in fact enhance recognition performance. Whether this advantage is of great enough practical significance to justify the additional cost of providing a display freeze (e.g., scan converter) capability is questionable. Although some image blur may be eliminated by this procedure, a considerable amount of blur due to motion is caused by the sensor (due to the frame integration time), and is therefore still present. In a frozen image, any blur due to scene motion during the frame time remains "correlated with" the scene, whereas in a dynamic image the observer's visual system can "integrate out" some of the blur. Also, although more time is available to inspect a scene, in some cases display freeze might result in an important target going undetected, if it should pass through the field of view while the display is frozen. The most useful application of display freeze is probably for missions being flown against fixed targets whose position is known. A computer tied in to an accurate navigation system could then provide display freeze as a predesignation technique (see Sturm, Snyder, Wyman, and Rawlings, 1966), thereby increasing recognition ranges.

4.2.12 Sensor Pointing Angle

Some attention has been given to the depression angle at which a sensor should be fixed in order to maximize detection or recognition ranges. Whenever feasible, it is clearly desirable to enable the observer to control where the sensor is pointing, so that a target, once detected, may be tracked regardless of the movements of the aircraft. In some systems, however, no such capability is provided. Furthermore, even when the camera can be controlled, it is likely to be set in a stationary position prior to target detection, while the terrain is being searched. Thus, some decision has to be made as to how far down from the horizon the sensor should be aimed in order to produce the best results. In order to answer such a question, attention must be given to other variables as well, such as camera field of view (FOV), aircraft altitude and speed, target type, etc. These factors must combine in such a way that the target can be detected and recognized before it passes beyond the lower boundary of the display.

A study by Carter (1962) utilizing FOV's from 10° to 26° found the optimal depression angle for recognition to be 30° at an altitude of 3000 ft (914m) and 20° at an altitude of 1500 ft (457m). Such a result is logical since, for a given FOV, the ground area being taken in by a camera decreases as altitude decreases. This effect can be compensated for by decreasing the camera depression angle, which results in an increase in ground coverage, thereby increasing the amount of time a target remains displayed.

Humes and Bauerschmidt (1968) studied camera pointing angle in conjunction with camera FOV and aircraft velocity/height ratio (V/H), in a fixed-base simulation study in which the observer viewed a TV display of motion picture scenes. At a low V/H value (0.05), recognition performance was poorest at a depression angle of 26°, better at 45°, and still slightly better at 82°. At higher V/H values, optimal performance was obtained at the 45° pointing angle, and poorest performance again was found at 26°. These results are presented in Figure 4-15. In line with Carter's (1962) results, it may be seen that the advantage of the more forward-looking angle (45°) is greater at the lower altitude tested. It is also evident from this figure that the lower velocity resulted in substantially improved recognition performance regardless of viewing angle in this simulation, although this effect was most pronounced for the "nadir" viewing mode (82°). Because of the interaction between the effects of pointing angle and altitude, the authors point out that the use of V/H as a summary measure of two independent variables is risky; it cannot always be assumed that an effect observed at a certain V/H value would also be observed at a different speed/altitude combination producing the same V/H level.

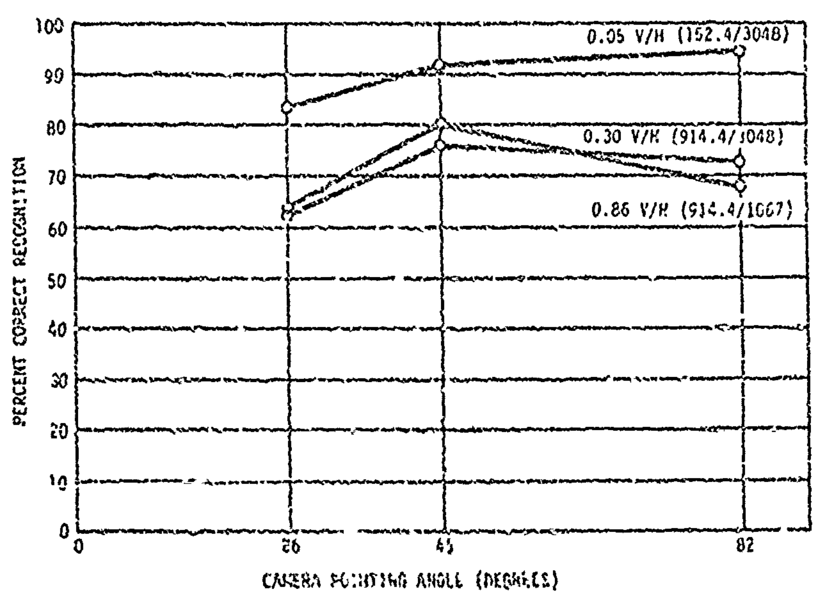


Figure 4-15. Percent Correct Recognition for Oblique and Nadir Viewing Modes: Camera Pointing angle by V/H interaction (V specified in meters/second; H in meters). (Redrawn from Humes and Bauerschmidt, 1968.)

The sensor FOV should also be taken into account when determining optimal pointing angle. Humes and Bauerschmidt found an interaction between FOV and pointing angle such that at a relatively shallow pointing angle (26°), recognition performance was best with a narrow FOV, but as the depression angle increased, larger FOV's were advantageous. Although these results depended somewhat on the particular performance measure being considered, the authors concluded that under shallow viewing angles a vertical FOV of 18° or less is advisable; for a pointing angle of 45° a vertical FOV of approximately 26° was recommended; and for nadir viewing angles a vertical FOV of approximately 47° appeared optima .

In summary, Humes and Bauerschmidt make the following conclusions about the operational significance of their results: "...optimum recognition performance for a fixed pointing angle system would be realized with a camera pointing angle in the region of 45°. With shallower angles, longer slant ranges are obtained, but lower percent recognitions result; with steeper angles (and shorter slant ranges), higher percent recognitions can be expected. Since varying operational requirements may be encountered in which either long acquisition slant ranges or high target acquisition probabilities may be of primary importance for given missions, it is concluded that a viewfinder system with variable camera pointing angle capability would be most desirable."

4.2.13 Scene Rotation

Closely allied to the topic of sensor pointing angle is the subject of displayed scene rotation. This topic, which has received no experimental attention until very recently, pertains to the false rotation of a scene displayed to an observer, as the result of line-of-sight rotation of a gimbal-mounted sensor. If a sensor is mounted beneath an aircraft, some type of gimbal arrangement is often provided in order to permit the camera to track a target whose position is changing relative to the orientation of the aircraft. A variety of such gimbal arrangements may be chosen. The final selection may be based on a number of engineering considerations other than those affecting the appearance of the scene as it is displayed to the observer.

Depending on the location of the target relative to the aircraft's flight path, certain gimbal arrangements will result in a line-of-sight rotation (roll) of the scene viewed on the display. The nature of this rotation is determined by the gimbal order chosen. In a 2-axis gimbal system, a yaw-pitch gimbal order (meaning that the yaw axis is the outer axis of rotation) produces no scene rotation, while a pitch-yaw order will produce rotation when the aircraft flies past a ground target that is offset from the flight path. At a given moment, the amount and rate of rotation depend on aircraft speed, direction of flight relative to the target, altitude, and distance from the target. As an example, consider the case where a sensor mounted on a pitch-yaw gimbal begins tracking a target seen at an azimuth of 340° relative to the aircraft's heading. If the aircraft maintains level flight, and the sensor continues tracking until the target is off the left wing (an azimuth of 270°), the displayed scene will rotate

in a counterclockwise direction. In the case of a roll-pitch gimbal order, the conditions described above would again result in counterclockwise rotation. However, the amount and rate of rotation observed at a given point during the flight would differ. Figure 4-16 presents a comparison of the rotation produced by the roll-pitch and pitch-yaw gimbal orders during a typical flyby maneuver.

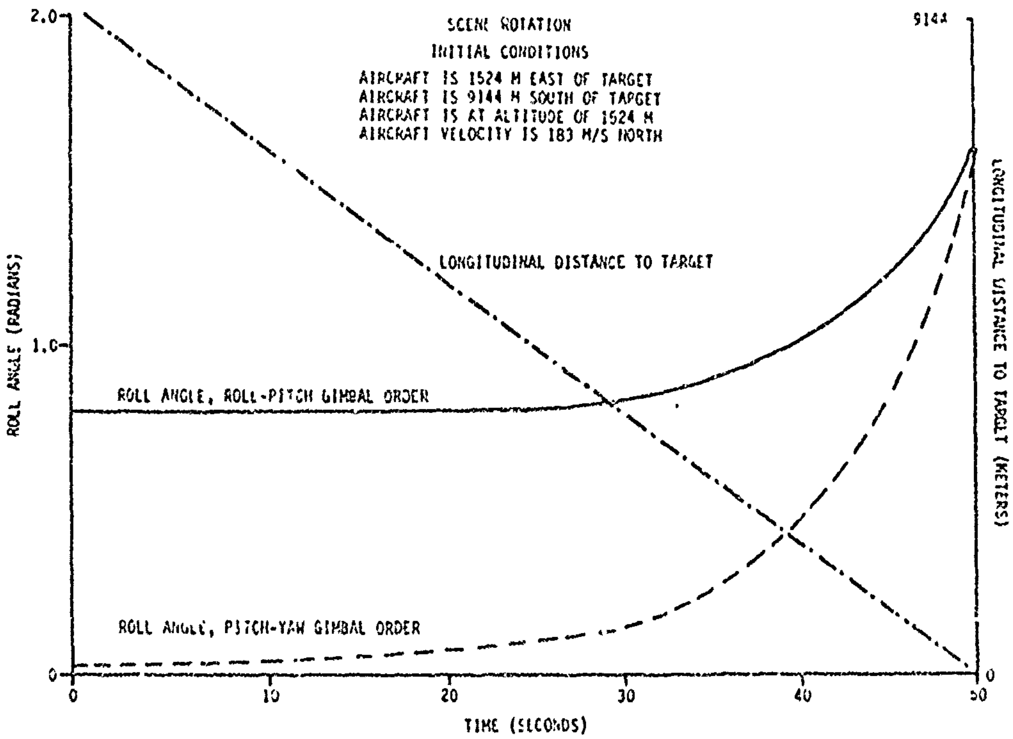


Figure 4-16. Comparison Between the Amount of Scene Rotation Produced by Two Gimbal Orders, During a Typical Flyby Maneuver

Freitag and MacLeod (1974) have recently completed an experimental program to study the effects of scene rotation on target acquisition performance. A terrain simulator was employed in conjunction with a TV camera mounted on a three-axis gimbal driven by a computer programmed to simulate either a yaw-pitch (no rotation) or a roll-pitch gimbal. Although the results showed no differences in detection performance, recognition slant ranges were significantly longer for the no-rotation condition. This is the first experimental evidence suggesting a decrement in acquisition performance due to scene rotation. Price (1974) essentially replicated this experiment and obtained the same results.

Further research will be required to observe a wider sampling of gimbal arrangements, as well as to determine the cause of this decrement.

One possible explanation is that the additional motion produced by the sensor rotation rate causes further image smearing, hence a decrease in target image quality. Another possibility is that targets are more difficult to recognize when seen in an unfamiliar orientation.

If scene rotation proves to be sufficiently disorienting or detrimental to pilot performance, it is possible to eliminate the rotation either by counter-rotating the display itself, or by employing electronic means. Either procedure has drawbacks, and further research must determine whether the advantages would outweigh the costs.

It should also be noted that target acquisition is not the only performance area which is likely to be affected by gimbal arrangement. Tracking, for instance, is much more difficult with a roll-pitch system than with a yaw-pitch system (Freitag and MacLeod, 1974).

4.2.14 Color vs. Black and White

Because black and white TV systems convert a scene into an image that varies only in luminance level, it seems intuitively obvious that a great deal of potentially useful information is being lost. Some authorities (e.g., Hillman, 1967) have suggested that acquisition performance should be improved substantially if this extra information were available to the observer, particularly when operating at low altitudes and in clear weather.

Only a few realistic studies have been designed to investigate the use of color TV systems in target acquisition. These studies have generally failed to demonstrate clear-cut differences in detection performance as a function of color contrast, although recognition and/or identification performance may be enhanced in certain instances. A review of the experimental literature on the effects of color on visual search, primarily for displays, was conducted by Christ and Teichner (1973). They concluded that while color can be an effective aid to performance under some conditions, it can be detrimental in others. If the observer has been briefed concerning the colors of certain classes of targets, his performance might improve.

One recent study of the ability of subjects to acquire colored military targets was performed by Fowler and Jones (1972). They investigated whether the use of a color television display would enhance detection or recognition performance over that achieved with a black and white TV picture. Using video tapes prepared by "flying" over a terrain model, they found no advantage due to the color display, regardless of whether the target colors were similar to, or different from, their background colors. Later research in the same laboratory employed lower target/background brightness contrast values than used in the earlier study. The results again failed to demonstrate any advantage due to the use of color displays.

An earlier simulation study (Snyder et al., 1964) comparing color with black and white film, arrived at essentially the same conclusion. No

significant differences were found in mean recognition ranges or percent correct recognitions, even when two of the five targets employed were yellow vehicles, which are seldom encountered in real life tactical environments. A similar conclusion was reached in a recent study by Davies (Parkes, 1972).

Because of the results of such studies and because of certain other considerations, it is doubtful whether presenting the observer with a realistic color picture of the scene is particularly advantageous in most air-to-ground operations. This is especially true considering the increases in cost and weight associated with color systems. One reason for the relative unimportance of color information is that the atmosphere reduces color contrast, imparting a bluish tinge to low-contrast objects (cf. Middleton, 1952). In general, as the distance between the object and the observer increases, colored objects become less saturated until they are virtually indistinguishable from achromatic objects. The range at which this occurs depends upon the amount of haze, the nature of any atmospheric contaminants, and the inherent saturation of the object. In many instances, the target and its background may be essentially monochromatic at the range at which an observer initially detects the target.

In addition, of course, most tactical targets are deliberately colored to match their probable surroundings as closely as possible, which further decreases the importance of color as an operationally significant variable. Furthermore, the dominant wavelengths of most natural objects appearing on the earth's surface lie within a fairly narrow range, which means that the range of color contrasts likely to be encountered in most missions is limited.

4.2.15 Aspect Ratio

Aspect ratio is usually defined as the ratio of the horizontal length to the vertical height of a display. In commercial television systems, the aspect ratio is 4:3. The effects of this variable have been studied in one experiment (Humes and Bauerschmidt, 1968), where it was found that orienting the vertical raster display so that its height was greater than its width resulted in a slight performance advantage. Aspect ratios of 1:1, 1:2, 3:4 were studied, where the total ground area covered was identical for the three ratios. The camera pointing angle was fixed, and was set to point either at an oblique angle or almost directly downward. The probability of recognizing a displayed target was found to be greater when display height was greater than its width; this effect was greater in the nadir viewing mode. This result is not surprising; since the target was in the field of view for a longer time, the observer's chances of recognizing it should be improved.

Although aspect ratio had some effect in the above experiment, it is not likely to be a particularly important variable. If the sensor is pointing down or straight ahead, it is true that a target will be displayed longer if height is the longer dimension. (Just the opposite is true for a side-looking sensor). However, it should be remembered that the total

number of targets displayed will be reduced, since some targets will now fall outsi e sensor's field of view. Whether or not these two effects would exa ounteract each other is not known; the answer would probably be differe depending on the target density, the aircraft V/H, and other variables. The appropriate experiment has never been done, and is probably not worth doing.

If a sensor/display system is being used as part of a guidance system for weapon delivery, where the target is first acquired by direct visual means and the sensor is then pointed at it, there may be a slight advantage to having the width greater than the height. This is because when the operator is trying to bring the target into the field of view, there is probably more positional uncertainty with respect to azimuth than elevation, since there are fewer possible elevation angles at which the target could be located. The reviewer knows of no data to back up this reasoning, however.

4.2.16 Raster Orientation

A few sources have suggested that target acquisition performance with line-scanned images might be ennanced if the raster scan lines were oriented in a vertical direction, contrary to common practice. The reasoning behind this suggestion is as follows. Most targets as seen from the air are elongated in appearance, so that their width is much greater than their height. One reason for this fact is that all objects seen at an oblique angle tend to be foreshortened -- for example, a circular lake seen at an angle assumes an oval shape. In addition, during an attack phase an aircraft would normally be flying toward the widest dimension of the target, in order to have a better chance of scoring a hit. It is also true that display resolution is very often superior (or at least continuous) in a direction parallel to the raster scan lines. It therefore makes logical sense to orient the display so that maximum resolution is in the direction where it is most needed -- namely, where the target spatial frequency is higher.

One factor which argues against this logic, however, is that vibration in airborne systems often limits the effective resolution in both directions, and tends to make horizontal and vertical resolution more nearly equal than they would be when measured statistically.

A study by Rusis (1966a) investigated the effects of raster orientation in a target recognition task, and found that vertical scan line orientation was superior to horizontal orientation. In this study, the simulated altitude was 1000 ft. (304.8m), so that considerable target foreshortening would occur. Furthermore, resolution in the direction of the scan lines was reported to be nearly tw that across the scan lines. Thus the result in accordance with the reasoning presented above.

In a more recent study, Bruns et al. (1972) investigated this riable with a TV system in which resolution was approximately equal in the two dimensions. The task involved detecting and identifying buildings

during simulated air-to-ground attacks. Small performance differences were again found, in favor of the vertical scan line orientation. The only statistically significant difference was for detection slant ranges (11% greater slant range for vertical orientation); identification ranges and probabilities were not significantly different. The difference is probably due to target motion, which was predominantly in a vertical direction. Motion should have less of a degrading effect when the target is continuously sampled (along the raster line) than when discretely sampled (across raster lines.) This result should be confirmed and studied for a v riety of mission profiles.

In vi[illegible] the small amount of data on this subject, design recommendat[illegible] [illegible] be made with caution. In systems where the difference betw[illegible] [illegible]zontal and vertical resolution is substantial, serious consideration should be given to orienting the display so that maximum resolution is in the vertical direction. On the other hand, if the resolution difference is small (keeping in mind that it will be further reduced by vibration), it seems unlikely that very large performance differences will result from changes in raster line orientation. Consideration should also be given to the type of task required of the observer. In the case of detection performance, it is probably true that most targets when detected are foreshortened in the vertical direction. However, in the case of target identification, it is not at all clear that the target detail necessary for identification has a much higher spatial frequency in the vertical direction.

4.2.17 Spot Wobble

In Section 4.2.3 the problems associated with raster line visibility were discussed. It was noted that whenever an observer sits close enough to a CRT so that the raster structure is clearly visible, he may not be able to perceive all the information presented to him because of the masking effect of the high-frequency horizontal lines. It is therefore desirable, especially in high resolution systems, to suppress the raster structure without degrading system resolution. The technique of spot wobble was developed for this purpose.

The basic objective is to [illegible] the blank spaces between each raster line. This could be done [illegible] [illegible]ng the scanning spot, but horizontal resolution would drop as a [illegible] An elongated spot is needed, whose height equals the raster line sp[illegible]ing, but whose width is relatively narrow. An irregular spot such as this is difficult to produce by electron optics, but the same effect can be achieved by making the spot oscillate rapidly in the vertical direction as it scans horizontally. The technical details and variations of the spot wobble technique will [illegible] covered here. Biberman (1973) presents a discussion of some of the te[illegible] aspects of the problem.

Although the spot wobble procedure has been known for some time, very few controlled experiments have been done to asses[illegible] [illegible] effectiveness. One study by Thompson (1957) was mentioned in [illegible]tion 4.2.3.

However, Thompson was concerned only with observers' preferences, not visual performance. He determined that spot wobble did indeed make the raster lines less visible, and that when subjects viewed static pictures they tended to choose viewing distances at which the lines just blended together.

RCA (1962) published an investigation of spot wobble in a terrain localization experiment. Subjects viewed static photographs which were prepared by taking aerial terrain photographs and processing them through a television simulator (essentially a closed-circuit TV system). Line coverages from 125 to 500 scan lines per frame were studied, with and without spot wobble. Subjects viewed TV images of terrain sectors, then tried to locate each sector in a photographic image of a larger scene. Under the conditions of this experiment, no improvement was found with spot wobble. A more operationally realistic experiment has very recently been done to investigate spot wobble amplitude effects on dynamic air-to-ground target acquisition. In this study (Beamon, 1974) a visually "soft", flat-field raster produced longer target acquisition ranges than did smaller amplitude or no spot wobble. The probabilities of target acquisition were not affected by the spot wobble amplitude.

The use of spot wobble cannot be strongly recommended on the basis of so little data. Clearly, much work remains to be done on this important topic. Nevertheless the technique is potentially useful and should be given consideration in any application where raster lines are visible at a typical viewing distance.

4.2.18 Image Enhancement

When an image is being created, a great many factors can operate together to degrade the quality of the finished product. Typically the contrast is reduced in comparison with the original scene, and the transitions (edge gradients) between areas of different luminance are gradual rather than abrupt. A number of video processing methods have been devised in order to enhance the contrast between a target and its background, and to sharpen a target's borders. The details of these techniques (which include gamma correction, contrast stretch, edge sharpening, differentiation, and optical filtering) will not be covered here. Brief descriptions of several available techniques may be found in reports by Hillman (1967) and Levi (1969). Brainard and Ornstein (1965) and Brainard and Caum (1965) describe several techniques for edge sharpening, which is the procedure given most attention in the target acquisition literature. The following paragraphs present results from a few target acquisition studies of image enhancement, involving dynamic and static imagery.

A study by Blackwell et al. (1961) has already been reviewed in Section 4.2.6, where it was shown that target detection performance improved as gamma was increased from 1 to 4. That study also investigated an optical spatial filtering technique, in which information at certain spatial frequencies was selectively eliminated. Limited success was achieved when the optical filters were used with aerial photographs; at best, some filters improved performance at low levels of detection

probability, but degraded performance at high detection probability levels. The authors concluded that optical filtering procedures are potentially useful, but that studies of a more analytic nature should be performed. Since then, optical filtering has not been studied within the context of human target acquisition, although it has been used extensively in automatic pattern recognition.

Some early work on the value of edge sharpening (subtracting from a video signal its second derivative) was performed by Brainard and Caum (1965). This technique is analogous to the edge-enhancing ability of the human visual system which gives rise to Mach bands (see Section 2.3.4). The authors investigated a variety of aerial photographs of tactical targets, and found that enhancement produced substantial improvements in several performance measures. Further, as the task difficulty increased, from simple detection to identification, the relative magnitude of the improvement increased. This is understandable, in that edge enhancement improves patterns with high spatial frequency content (e.g., small details in the image), which is important for target identification.

Results of a study by Rusis (1966) also indicate that image enhancement by an edge sharpening technique can be beneficial, but that the amount of improvement depends on other factors. Proportion of correct recognitions increased and incorrect recognitions decreased, when image enhancement was present. In general, the beneficial effect of enhancement was greater at short slant ranges, and for heavily masked targets in comparison with moderately or lightly masked targets.

Another investigation of edge sharpening was conducted by Humes and Bauerschmidt (1968). Subjects searched for tactical targets while watching a dynamic scene. This study showed that the amount of enhancement may determine whether performance is improved or degraded in a particular situation, and that signal-to-noise ratio must be taken into account. It was found that a medium (1:1) level of enhancement produced faster recognition speeds than zero enhancement, or a high (3.5:1) enhancement condition. The same trend, although not statistically significant, was found for other performance measures. Furthermore, when S/N ratio was high, a high degree of image enhancement was beneficial; but at relatively low S/N levels, performance worsened as image enhancement increased. This happened because the type of enhancement employed (second derivative subtraction) tends to enhance the noise at least as well as the signal. The authors concluded that if this technique is used, the operator should be given the capability to control the degree of enhancement.

In summary, image enhancement techniques are considered to hold promise, although the degree of improvement is situation-dependent. The amount of relevant target acquisition data is still small, however. In deciding whether to use image enhancement, or which technique to use, the designer must determine as precisely as possible the target and environmental conditions for which the system will be used. Of course, it is not always possible to do this with any degree of certainty. As Blackwell

et al. (1961) point out, a system designed to provide a specific type and degree of enhancement will be limited in its u fulness, but that a system with great flexibility requires considerable training in its use and places greater demands on the operator.

4.3 Summary Measures of Image Quality

For a number of years there has been a recognized need for an overall measure of image quality that can provide a means of predicting observer performance with realistic targets viewed on a display. In recent years several workers have made significant advances in simplifying the specification of image quality by combining several parameters that affect observer performance into a summary measure. In this section two such attempts which appear highly promising will be reviewed. It will be seen that although they were developed in different fashions, and may be used in different ways, they are actually quite similar.

The basic approach of these techniques will be described, and the results of some perceptual experiments to validate them will be presented. In addition, their advantages and limitations will be discussed in terms of their ability to predict target acquisition performance with various types of imagery.

4.3.1 Display Signal-to-Noise Ratio (SNR_{DI})

The concept of the display signal-to-noise ratio (SNR_{DI}) is a promising, recent attempt to provide a summary measure of image quality that can be used to predict the visibility of a specific target which is imaged on a display. Much of the work of developing and validating SNR_{DI} has been done at Westinghouse by Rosell and Willson; their work is based on earlier research by Coltman and Anderson, Schade, Rose, and others. A recent description of the research on SNR_{DI} is an article (Rosell and Willson, 1973) which appears as a chapter in "Perception of Displayed Information," edited by L. M. Biberman.

The basic approach is to consider a set of interrelated factors that have an effect on observer performance, and to combine these factors in an equation that can be used by system designers to calculate whether particular targets can be detected, recognized, or identified. The approach is also valuable as an analytic tool for comparing performance between different sensors with respect to characteristics that really affect observer performance -- thus reducing the need for expensive laboratory evaluations. This report will not discuss the details of the equations, or the way they were derived. There are many versions of the same basic equation, which are appropriate in particular situations. For the reader interested in these details, the best source is probably Rosell and Willson (1973) (also see, Rosell and Willson, 1971). In essence, the equation starts with the video signal-to-noise ratio (SNR_V). This quantity can be

measured electronically, prior to being inputted to the display, as the peak-to-peak target signal divided by the rms noise level. The SNR_V is then modified to include bandwidth, visual temporal integration time, the size of the target as it is imaged on the photosurface, and the size of the photosurface itself. The resulting formulation may be written as

$$SNR_{DI} = [2t\Delta f_V(a/A)]^{\frac{1}{2}} \cdot SNR_V \qquad (4.7)$$

where SNR_{DI} = image signal-to-noise ratio on a hypothetically perfect display

t = visual integration time (assumed to be 0.1 second)

Δf_V = video bandwidth in hertz

a = target image area at photosurface

A = total area of photosurface

SNR_V = video signal-to-noise ratio.

This equation shows that by increasing the size of the target as it is imaged on the photosurface, it is possible to decrease the video SNR and still maintain the same SNR_{DI}. If it could be shown how the level of SNR_{DI} required for perception is affected by the size of the target, then this measure would be useful to designers as a means of specifying the trade-offs necessary for achieving a given level of performance. It will be seen that threshold SNR_{DI} is very nearly a constant over a considerable range of target sizes.

It should be emphasized that the SNR_{DI} approach is used to calculate image quality for a target of a specified size; it is not an overall measure like the MTFA (to be discussed in the following section), which describes image quality over a range of spatial frequencies. The SNR_{DI} is calculated for the particular frequency of interest, which is one of its virtues for practical applications. Thus it may be used, for example, as a means of calculating the camera field of view necessary to make the image of a tank large enough to be detected at a particular distance.

Rosell and Willson (1973) report on a large number of psychophysical experiments investigating perceptual ability as a function of the calculated SNR_{DI}. In the first phase of this research they studied threshold detectability of aperiodic targets, such as single rectangles and squares. They found that for these targets SNR_{DI} was a reliable predictor of performance; as the size of the targets was changed considerably the SNR_{DI} required for .50 probability of detection stayed very nearly the same.

Thus, as the target area increased, subjects could tolerate a greater amount of noise and still maintain the same level of performance. Once the width of the rectangle or square subtended more than about 0.5° at the observer's eye, a greater SNR_{DI} was necessary; below that level, however, it remained nearly constant at a value of approximately 2.8.

Detection performance was also studied with a series of periodic (bar pattern) targets. With these targets it was found that the SNR_{DI} needed to discern the patterns on 50 percent of the trials decreased slowly as the spatial frequency of the bars increased. This result is illustrated graphically in Figure 4-17. It should be noted that the calculation of SNR_{DI} was based on the total area of a single bar in the pattern.

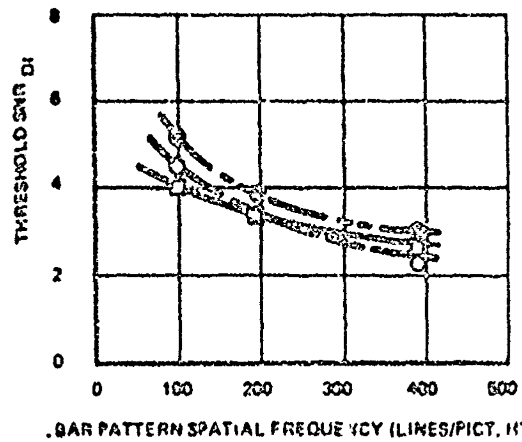


Figure 4-17. Threshold SNR_{DI} versus Bar Pattern Spatial Frequency for Three Bar Height-to-Width ratios of (□) 5:1, (◇) 10:1, and (○) 20:1 (from Rosell and Willson, 1973).

Rosell and Willson next conducted a series of recognition and identification studies, in which static images of military vehicles were viewed against either a uniform background or a terrain background. The approach here was to determine the SNR_{DI} level needed for a given level of performance when viewing the actual targets, and to relate this to the SNR_{DI} needed to detect bar patterns whose frequency was determined from Johnson's criterion (see Section 4.2.1, especially Table 4-I). For example, Johnson found that, on the average, a target could be recognized when its minimum dimension was eight times the width of a bar in a just discriminable bar pattern. Therefore, in calculating the SNR_{DI} of the vehicular targets, the area (a) was taken as the area of a rectangle whose length was the same as the vehicle, and whose width was 1/8 that of the vehicle. The area (a) for the equivalent bar pattern had the same numerical value, as it was also based on the width of a single bar.

The result of these experiments was that, when SNR_{DI} values were calculated in the manner described above, the SNR_{DI} required to recognize or identify a real-world target was very nearly the same as that required to discern the equivalent bar pattern. This, in essence, confirms Johnson's finding that there is a consistent relationship between the two kinds of targets. As Rosell and Willson point out, the reason for basing the SNR_{DI} calculations on the Johnson criteria is so that the image detail can be expressed in terms of a spatial frequency; thus, the amount of drop in the signal amplitude at high spatial frequencies (due to the aperture response of the sensor) can be calculated and used in the determination of SNR_V.

The results of the above series of experiments are presented in Table 4-IV. This table presents the best estimate currently available for the SNR_{DI} required for various levels of discrimination. The third column presents the bar pattern density which was used to calculate SNR_{DI}; the remaining four columns present required SNR_{DI} for targets of different sizes, expressed as the spatial frequency of the equivalent bar pattern. The threshold values given are for 0.50 probability of correct performance; to convert to another probability level, Figure 4-18 may be used. It should be noted that as either the discrimination level or the background complexity increases, the variability in SNR_{DI} also increases, hence accuracy of performance prediction decreases.

TABLE 4-IV

Best Estimate of Threshold SNR_{DI} for Detection, Recognition, and Identification of Images (from Rosell and Willson, 1973)

Discrimination	Background	K_d ** TV Lines per Minimum Dimension	Threshold SNR_{DI} for a Single Bar of Spatial Frequency (in lines/picture height) Equal to			
			100	300	500	700
Detection	Uniform*	1	2.8	2.8	2.8	2.8
Detection	Clutter	2	4.8	2.9	2.5	2.5
Recognition	Uniform	8	4.8	2.9	2.5	2.5
Recognition	Clutter	8	6.4	3.9	3.4	3.4
Identification	Uniform	13	5.8	3.6	3.0	3.0

* Treated as an aperiodic object.
** (Johnson's criterion)

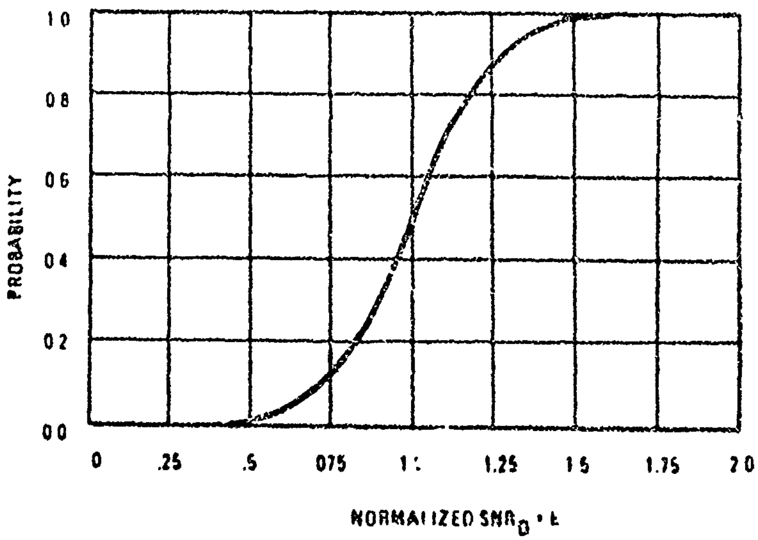


Figure 4-18. Probability versus Normalized SNR . For any probability value, obtain SNR_{DI} from Table 4-IV for 50% probability. Find value of k for desired probability and multiply value of SNR_{DI} by k to obtain new value of SNR_{DI} required (from Rosell and Willson, 1973).

Note that the above technique for determining whether the required level of performance will be achieved in a given situation has certain advantages over the application of Johnson's criteria (as described in Section 4.2.1), even though it is partly based on those criteria. To begin with, it is more objective, for it does not require actually determining the limiting resolution of the system, as must be done in order for Johnson's criteria to be applied. (The procedure for determining the limiting resolution is inherently unreliable, since it is based on subjective observations, a small number of observers, and nonstandardized test protocols.) Instead, SNR_{DI} can be directly derived from physical parameters of the system, the target, and the environment. A second advantage is that this predictive measure incorporates video SNR, which is known to affect performance (see Section 4.2.7). Johnson, on the other hand, merely specified that SNR must be "sufficient" in order for his approach to be valid, a requirement that is sometimes overlooked by those applying his criteria. Third, Johnson also specified that the contrast of the resolution test pattern be the same as that of the target; as discussed in Section 4.2.1, this requirement is also sometimes forgotten. In the case of SNR_{DI}, however, this does not present a problem since target contrast enters into the formulation of SNR_V.

It should be clear from the brief treatment given to SNR_{DI} in this section that it is potentially a very useful approach to specifying and predicting image quality. For instance, if a designer is able to make

some assumptions about target size, target and background reflectances, level of scene irradiance, and atmospheric transmission factors, he could calculate whether a particular sensor field of view would be adequate for identifying the target at a particular range, when those system parameters that would determine SNR_V are known. This approach could also be used to compare the performance of different sensors in specific situations. An example of this application is provided by Rosell (in Biberman and Nudelman, 1971, Vol. 2), who calculates SNR_{DI} for five different types of sensors. It should also be noted that although SNR_{DI} is generally discussed in the context of television systems, it may be modified for use with infrared systems. For the details of this modification, see Sendall and Rosell (1972).

Finally, it is appropriate to point out that the concept of SNR_{DI} is still relatively new, and that a great deal of further work is required to refine it and to extend its usefulness. For example, Rosell and Willson note that there are differences in the way signal amplitude was measured for the vehicular targets and the bar patterns. Techniques may eventually become available which minimize these differences and increase the correlation between threshold SNR_{DI} values for the two kinds of targets. In addition, of course, much can be done to investigate a wider range of targets, seen against a greater variety of backgrounds, with more realistic tasks required of the observer, etc. Some of this effort involves extending Johnson's criteria, since calculation of SNR_{DI} depends on knowledge of the equivalent bar pattern.

4.3.2 Modulation Transfer Function Area (MTFA)

The modulation transfer function area (MTFA) is another summary measure of image quality that has recently been shown to be a good predictor of observer performance with line-scanned imagery. Unlike SNR_{DI}, this concept was originally developed for use in the photographic industry (see Charman and Olin, 1965; Borough, Fallis, Warnock, and Britt, 1967), and was later extended for use with electro-optical systems. Although the differences between MTFA and SNR_{DI} are numerous, it will be seen that ultimately they are closely related.

The MTFA is a way of expressing image quality in relation to the visual requirements of the observer. Although the modulation transfer function (MTF -- see Chapter 2) is a valuable technique for describing the ability of a system to transmit an image, it says nothing about the quality of that image as it relates to what is needed by the observer in order to extract information. For example, two TV systems with identical MTF's, yet with different gammas or different amounts of noise, may not be identical with respect to observer performance. The MTFA attempts to account for these differences by incorporating a measure of the observer's threshold sensitivity for patterns produced by the system being evaluated.

Figure 4-19 shows that the MTFA is the area in between the system MTF and the detection threshold curve of an observer viewing patterns imaged by that system (or under predicted conditions typical of that system). The system MTF may be determined readily, according to established procedures. The threshold curve, however, is often difficult to determine other than by testing a number of subjects under the conditions being evaluated; this is one reason why the MTFA is not yet widely employed as an evaluative tool. In the case of photographic research this problem is not too severe, for some generalized threshold curves are available, which may be adjusted according to known parameters. For example, the system gamma affects the shape of the curve at low spatial frequencies; object contrast modulation affects the vertical positioning of the curve; and film granularity affects its horizontal positioning (see Snyder, 1973, for a brief discussion of these adjustments).

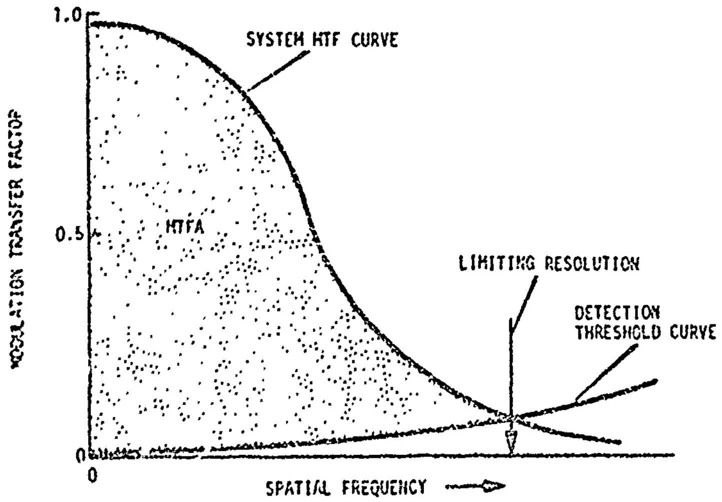


Figure 4-19. Modulation Transfer Function Area (MTFA) (From Snyder, 1972).

With respect to line-scanned imagery, however, no simple procedure is now available for estimating these curves; instead, they currently must be derived empirically. There is a need for an extensive set of such curves, covering a wide variety of imaging system characteristics, which may be utilized by those wishing to make MTFA calculations. Workers in Snyder's laboratory at VPI have made considerable progress in this direction, and this research is briefly summarized below.

The most extensive study to determine line-scan contrast thresholds has been that of Keesee (1972). He determined system square-wave responses and threshold functions for a TV system operated at three combinations of bandwidth and line density: 32 MHz with 1225 lines per frame; 16 MHz with 945 lines; and 8 MHz with 525 lines. For each of the above combinations, detection thresholds were found for a variety of noise passbands, target

modulations, and target spatial frequencies. It is important to note that these experiments were conducted, not with sine wave patterns, but with square wave (USAF tribar) targets. This was done largely because of the difficulty of producing accurate reproductions of sine wave intensity variations. (Any MTFA calculated on the basis of square-wave data will be designated $MTFA_{SQ}$.)

Figure 4-20 presents some representative data from Keesee's study. Obtained with the 32 MHz/1225 line system, and a noise passband of 0-20 MHz, these data illustrate the relationships found throughout this experiment. As expected, the amount of noise that must be added to the signal in order to obscure the tribar pattern will increase as the target modulation increases, and as the target spatial frequency decreases. Although some of the curves show a leveling-off at higher modulations, Keesee showed that linear regression equations fit the data well, with multiple correlation coefficients of 0.90 or higher.

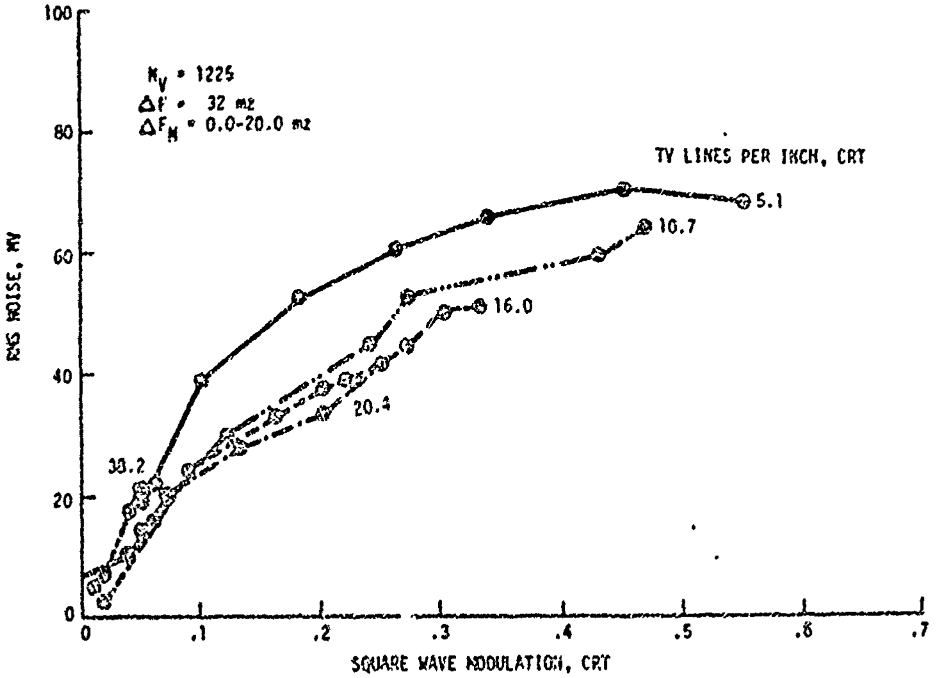


Figure 4-20. Detectability Threshold Means
(adapted from Keesee, 1972).

This study represents an important first step in developing a data base for the calculation of MTFA under a variety of conditions. But as the author points out, the data are still of limited usefulness, due primarily to difficulties in controlling and measuring beam spot size and raster stability. Thus at the present time the information is not available for determining the MTFA of a particular system, without actually performing the necessary psychophysical experiments using that system.

In spite of the difficulties in calculating the MTFA, recent experimental work has shown that it correlates well with measures of observer performance. Thus, it appears to be a valid indicator of overall image quality. Experiments to establish this relationship have been performed both with photographs and with television images. The photographic work, summarized by Snyder (1973a), has shown that the MTFA correlates highly (i.e., above 0.90) with (a) subjective estimates, made by trained image interpreters, of the quality of reconnaissance photographs; and (b) the ability of observers to extract information from these photographs (Borough et al., 1967; Klingberg, Elworth, and Filleau, 19?0).

In the case of line-scanned imagery, evaluation of the validity of the MTFA has involved correlation of the $MTFA_{SQ}$ with observer performance, both with dynamic aerial reconnaissance films and with static photographs of human faces (Snyder, 1972). In the first study, subjects were asked to search for pre-briefed targets while watching films on a closed-circuit TV system with one of five levels of noise added to the picture. The results, when averaged over all subjects and targets, showed that the $MTFA_{SQ}$, calculated at different noise levels, was correlated highly with the probability of target recognition (0.965); the correlation with recognition slant range was substantially lower (0.76). In the facial recognition experiment, subjects tried to identify the face displayed, by comparing it with faces in a set of 35 pictures. A variety of line numbers, bandwidths, and noise levels were studied. Again, the averaged performance scores showed good correlation with $MTFA_{SQ}$, in terms of both accuracy and speed of response.

These experiments have demonstrated that the MTFA concept, modified for application to video systems ($MTFA_{SQ}$), is a reliable and valid overall predictor of how well subjects can extract information from a variety of image shapes, sizes, contrasts, etc. The problem, however, of predicting performance with any one particular target is much more difficult. To date, attempts to distinguish among targets by calculating MTFA's for particular targets and correlating these with performance have not been very successful. There is no ready solution to this problem, for it is basic to any technique that relies simply on some measure of average modulation, and ignores the many small internal details of the target, on which the subject often bases his discriminations (these problems are, of course, equally inherent in the SNR_{DI} concept.)

Finally, it is interesting to note the similarity between MTFA and another image quality measure, SNR_{DI} (cf. Section 4.3.1). Although they seem better suited for different purposes, Snyder et al. (1973) have noted that the two measures can be shown to be closely related, and hence probably are equally valid measures of overall image quality. Their analysis, based on earlier work presented by Biberman et al. (1971), is illustrated by the curves presented in Figure 4-21. The shaded areas in the two curves are equivalent, showing that the difference between a system's SNR_{DI} and the observer's threshold SNR_{DI} requirement, integrated across all usable spatial frequencies, is similar to that system's MTFA. The above is strictly true only if

the MTFA is based on sine-wave (not square-wave, patterns, if gamma is equal to 1.0, and if optimum viewing conditions, viewing times, and display magnifications are assumed. This result does not suggest that the two measures may be used interchangeably, but merely that they can be viewed within a common framework. For the present, at least, it appears that both measures have their strong features that make them better suited to answer different types of questions. The MTFA can be used to answer such a question as: "Which system, on the average, will result in the best operator performance with a variety of targets, seen at various distances?" Since the MTFA is a composite score for a wide range of frequencies, it can deal with questions where target spatial frequencies are unknown or unspecified. Such questions are important in the early stages of development of systems that are designed for general applicability in many different scenarios, or for an overall estimate of system utility for situations in which the user's applications are ill defined.

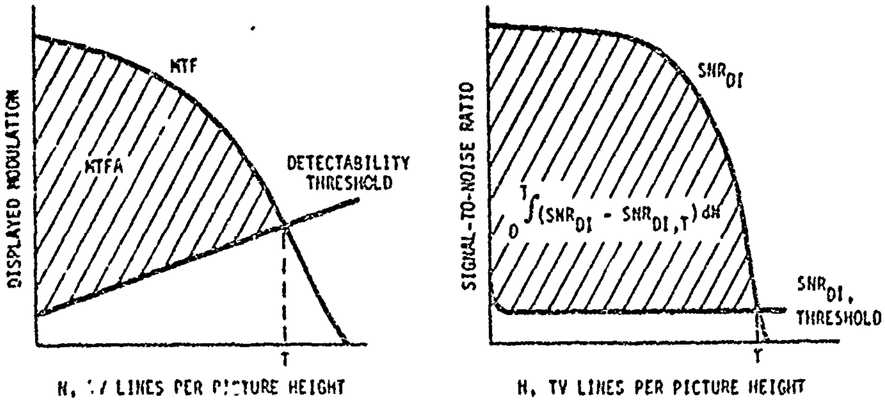


Figure 4-21. Comparison of SNR_{DI} and MTFA (from Snyder et al., 1973).

The SNR_{DI}, on the other hand, appears better suited to answer a question of this type: "Will this system permit a tank to be recognized at 3 kilometers?" If Johnson's criterion is known, the SNR_{DI} can be calculated on the basis of the target's equivalent bar pattern, and the result compared with the empirically-determined threshold requirements for that type of task (cf. Table 4-IV). The ability to answer this type of question is, of course, also valuable to system designers in many instances. The selection of which measure is used depends upon the design or evaluation objective of the user. Thus at the present time both these measures have considerable utility, and both should be developed further in order that their applicability and precision may be increased.

4.4 Summary and Conclusions

This report has presented research results concerning the effects of many imaging system parameters on target acquisition performance. Some

of these parameters were shown to be of great importance, while others were found to have slight or uncertain effects on the observer's proficiency. Often the results from different experiments did not totally agree; in most cases several variables were found to interact in a complex fashion, so that simple conclusions seldom emerged. Throughout this report the attempt has been made to show where the data were most needed, and where additional research effort should be directed. Of course, it is axiomatic that every area needs more study; reports are never ended without the statement that further research is necessary. Nevertheless, it is possible to assign priorities. The following list presents a few areas where further human factors research may result in substantial improvement in target acquisition capabilities, or where additional data may be of benefit to the greatest number of designers or researchers.

- As indicated in Section 4.2.1, the approach taken by Johnson (1958) should be extended to more situations. The equivalent bar pattern for detection, recognition, and identification should be determined as a function of such variables as target background type, viewing perspective, target motion, search requirements, and viewing time limitations. Such a program of research would be valuable not only because it would permit the application of Johnson's criteria in more representative situations, but also because it would extend the usefulness of the SNR_{DI} concept, which presently bases many of its calculations on Johnson's criteria.

- Effort should be continued on the development and refinement of summary measures of image quality, such as those discussed in Section 4.3, in order to increase their reliability and validity as predictive tools.

- The usefulness of the spot wobble technique should be explored further in a target acquisition program. As discussed in Sections 4.2.3 and 4.2.17, the use of some technique such as this to decrease the visibility of the raster structure on a display may permit the observer to gain additional information that was previously being masked.

- The related topics of frame rate (Section 4.2.8) and image frame integration time (Section 4.2.10) should be given further study. Realistic experiments should be done to determine those operational conditions under which frame rate can be safely reduced without substantially degrading performance. At the same time, the consequences of reducing image frame integration time should be studied, as a way of decreasing image smear when the frame rate is too slow.

Other reviewers have their own ideas as to where the research efforts should be focused. Hairfield (1970) has summarized a large number of classified and unclassified studies, and has assigned research priorities to the parameters he covered. The following quotations represent his thoughts concerning the five imaging system parameters to which he assigned the highest priority.

"Signal to Noise Ratio. The experimental literature suggests that acquisition performance is significantly degraded when the signal

to noise ratio drops below a value which lies somewhere between 16 and 25 db. Additional research is required to determine signal to noise ratio requirements.

"Horizontal Resolution. The experimental literature does not indicate the point at which recognition performance reaches asymptote as horizontal resolution is increased. Horizontal resolution should be studied in interaction with vertical resolution.

"Number of TV Scan Lines Subtending the Target. The scan line requirements for target acquisition which are assumed in a number of mathematical models are based on meager data from early research and need additional study. This scan line measure of vertical resolution should be studied in interaction with the variable of horizontal resolution. Also, data are needed concerning the interaction between the requirements for resolution and those for target angular subtense, signal to noise ratio, and search time.

"Display Size. Display size requirements are often based on 'rule of thumb' figures taken from early studies which related resolution, viewing distances, and display height requirements for TV entertainment viewing. Display size should be studied in interaction with these same variables with emphasis on viewing requirements for target acquisition.

"Field of View. The experimental literature indicates that a display which provides a horizontal field of view which is variable from about 3 to 50 degrees will provide adequate scene coverage for both target acquisition and flight control functioning. However, very little is known about the optimum values within this range for specific tasks such as aerial refueling, terrain avoidance, and landing. Additional data are also needed pertaining to the usefulness of the dual field of view concept in which the area surrounding the crosshairs is expanded and presented in one of the corners of the display."

The preceding list was presented as an illustration of a somewhat different viewpoint, although the present reviewer is not in complete agreement with this selection -- particularly with regard to horizontal resolution. It is felt that this parameter can now probably be better handled in the context of the summary image quality measures discussed in Section 4.3.

Erickson (1971) has also made a number of recommendations, specifically with regard to television/research. His listing of both general and specific suggestions concerning the direction of future target acquisition research is presented in part below.

1. Only multi-variable research should be supported. Experiments should include several levels of important factors, e.g., targets, velocity, and briefing. These levels need not all be encountered in any one application, but their inclusion would broaden the applicability of the results.

2. Research should be conducted to relate engineering characteristics and so-called summary measures of TV systems to the usefulness of the system.

   Contrary to popular opinion, this relationship is not well established. Some evidence indicates that once above some lower boundary, image quality has a small effect upon performance compared with other system parameters.

3. Standardized test material must be specified and produced for use by all researchers. These tests would be used to describe the TV system being used in the research. Procedures must be defined for gathering and presenting these standardized system descriptions.

4. A range of evaluation tests should be devised, which would consist of measures of system usefulness rather than engineering characteristic specifications.

5. Until performance is highly predictable from engineering characteristics (if ever), good quality photographs of primary imagery and TV display used in experiments should be included in every research report.

Specific studies which would be done (under Recommendation 2) are:

1. The definition and measurement of target-background contrast should be standardized in psychophysically meaningful terms.

2. An improved method for measuring and specifying contrast rendition, or shades of gray of TV systems should be developed.

3. A series of studies should be conducted to establish the variation in operator performance as a function of the variation in interlace and frame rate. Commercial values have been accepted in many military systems; although expedient, this may not be the most optimum procedure.

4. An analytic and experimental program should be conducted to develop psychophysically meaningful definitions of noise in TV systems. Current definitions do not include frequency and structure of the noise (visual structure) as related to the scene being viewed.

5. A study should be conducted to analytically describe the effects of motion on TV, and to verify the predictions experimentally.

6. The validity in extrapolating static data to the dynamic condition has not been established. The relationship between operator performance on static imagery and performance on dynamic imagery should be defined.

In conclusion, a reminder is perhaps in order, as a way of keeping the material covered in this chapter in its proper perspective. Much of the work discussed here has shown that without question a number of imaging system parameters strongly influence the observer's target acquisition performance. Nevertheless, it should not be forgotten that there are other factors (cf. Chapters 3 and 5) that are even more important in determining the observer's overall level of performance. Some of these factors are of such overriding significance that slight variations in them can easily mask the effects of many variables discussed in this chapter. The implication of this fact is that the people who do experiments and who are responsible for providing designers with human factors data need to be sure that the data they provide are representative of the type of task for which the system is designed. Essentially this amounts to a plea for: (a) high realism in the experiments performed, by employing terrain tables, high-resolution motion picture simulation, or live flights when feasible; (b) multi-variable research in which the relationships between several critical variables may be determined; and (c) caution in preparing summary charts and nomographs which overly simplify the data, thus presenting a risk of being used inappropriately.

CHAPTER FIVE

VISUAL SEARCH

5.1 Introduction

Search is necessary when a target cannot be located immediately. If a target is perceptually prominent it usually will be detected with little search required. The subject of interest in this chapter is direct visual search of the target area by the observer; what variables affect the search and acquisition of targets? While this chapter is largely concerned with operational-type data it also notes that laboratory data necessary to help understand the problem. The emphasis is on the operator and his "sensor", the eyeball, in visual search. Those variables in the target, geometry and environment areas that affect search performance are noted. Finally, the secondary variables that may affect the search process and the possible aids to search are considered. At this point a quote from Morris is worth noting: "Other sensor systems might supplement, but will never supplant the human eye strategically and tactically". (Morris, 1959, page vi).

There are three general types of target acquisition search situations (Teichner and Krebs, 1972):

(1) The observer knows approximately where the target is located, but does not know when it will appear. This is a condition of temporal uncertainty. When the target does appear it is usually of relatively short duration and can be easily missed if the observer is not searching at that location and at that time.

Operationally in this, the line search situation, the observer is searching for a known target or along a known route for expected targets. Thus, when searching for a bridge which has a known location it may be necessary to fly in at a low level or by a defiladed route. When the bridge "appears" it is unmasked for only a short time. Similarly when engaged in route reconnaissance the observer will search along a known road or trail for a vehicle on that route. In both cases the available time to acquire is short. If the observer is not "set" to find a certain type object and is not looking at the most likely location, the target may be missed.

(2) The target is known to be in a certain area, but its exact position is unknown. In this situation the target usually remains in position at least until it is detected. What is unknown is its exact location. Operationally this is the area search situation. Search for known targets somewhere in an area is typically that of pin-pointing the location of a surface-to-air missile or gun position in a wooded area.

(3) The third situation is when the target is unknown in both location and time. Operationally this situation is often considered typical of most search operations. Actually, it is really very rare that nothing is known about the area to be searched or about the target for which the observer is searching. When this does happen, the actual probability of finding targets can be expected to be very low.

5.2 Search Patterns

Observers all have both natural and learned search patterns in the process of target acquisition. Search patterns consist of a sequence of visual fixations, eventually stopping at the target. Figure 5-1 diagrams the general process of search (Williams, 1973).

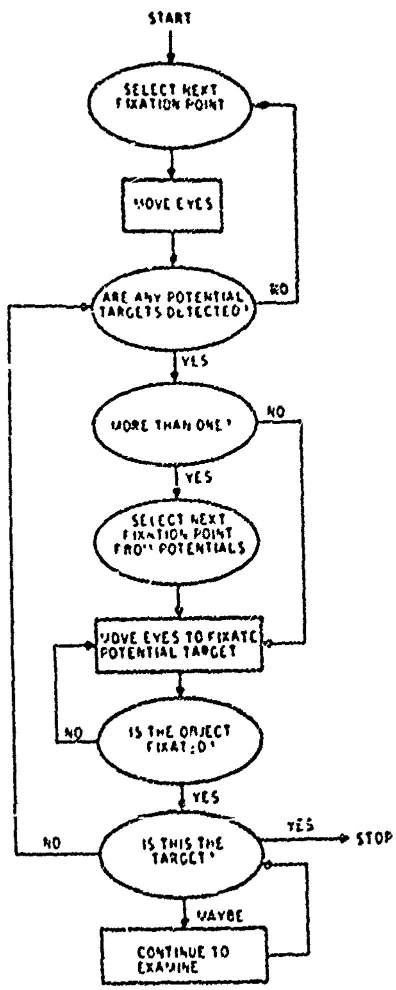


Figure 5-1. The General Search Process

5.2.1 Natural Patterns

The natural patterns of search depend upon the fixations of the eye. When an observer is engaged in visual search he does not scan smoothly over the area, although that is his subjective impression. Instead his eyes jump rapidly from one position to another. During the jumps (saccades) the retinal image is blurred and there is a reduction in visual sensitivity. We acutely perceive the visual field only when we fixate. As a result a number of studies have been directed toward investigating the pauses or fixation periods between saccades as this process affects target acquisition.

Data from Williams (1966, 1967) show that the path of movement of the eyes and the stopping point during visual search are largely determined before the movement begins. He suggests that the centers of subsequent fixations are usually chosen on the basis of what is seen peripherally. When searching for targets observers tend to look at (fixate) objects which appear to have the specifications (size, shape, contrast, color) they expect the target to have.

Laboratory data indicate that the mean fixation time approximates 0.33 second for large (50 to 90 degrees, visual angle) display areas. (Ford, White and Lichtenstein, 1959; White and Ford, 1960; Enoch, 1959). For small displays (under 9 degrees, visual angle) the mean duration of fixations increased sharply to 0.60 second. Enoch (1959) also found that for a small display area (less than 9° visual angle) a high percentage of fixations fell outside the search area (almost 50 percent for a 6° display and 75 percent for a 3° display). Enoch suggests that there are at least two natural phases to search. First, in an orientation phase observers tend to repeat a characteristic random pattern of fixations. In the second phase, they either use possible cues or expand the basic search pattern if no cues are present.

Eye-movement patterns in air-to-ground target acquisition when using a motion picture simulator dynamic display have been reported by Snyder (1973). A high proportion (80-90 percent) of the fixation points fell in a small portion (5 percent) of the visual scene. These fixations were concentrated near the horizon in the center of the field of view. The eye fixations tended to occur in certain types of terrain (e.g., clearings, roads) rather than in random or geometric patterns. The subjects who tended to have shorter eye fixation times also tended to report longer target acquisition ranges.

Four observers flew a motion picture simulation low level (200 feet or 61 meters altitude) prebriefed target acquisition mission at 360 knots (667 Km/HR)/speed. A wide-angle projection of JTF-2 test films was used. Eye movements were recorded for the right eye only. Results indicate that observers with shorter fixation times tended to be superior in target acquisition, although the small sample does limit this inference. Fixation durations were about the same as those reported by White and Ford (1960), i.e., 0.30 to 0.40 second. The search patterns were also related to target and terrain characteristics; 75 percent of all fixations were on objects the

observers reported as being related to the searched-for target. Thus, Snyder concludes that the characteristics of the target surrounding area are at least as important as the target in directing eye movements. Figure 5-2 shows a typical plot by Snyder of eye fixations in frequency and duration, as compared with that of White and Ford.

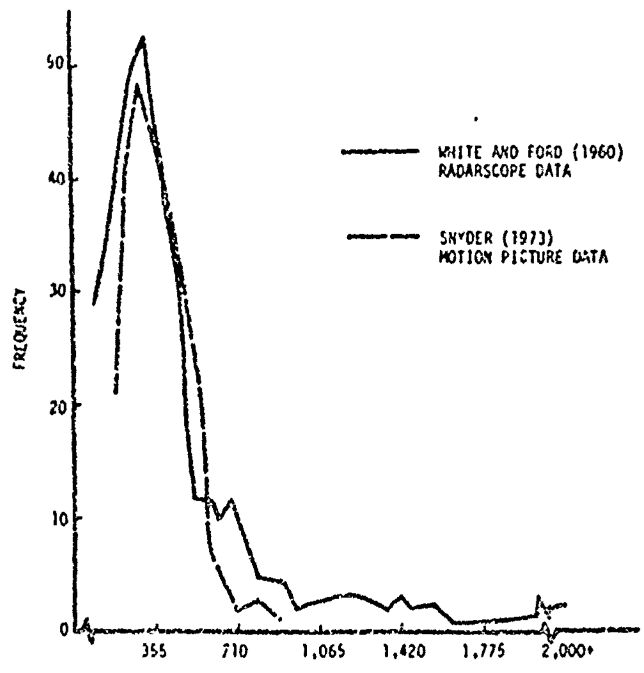


Figure 5-2. Frequency Distribution of Eye Fixation Times

In-flight studies of eye movement during actual field tests of target acquisition have not yet been reported.

The questions of interest are yet unanswered: How much performance improvement could be obtained by training observers in more efficient eye movement patterns? Can natural rates of eye fixation be used to help select superior target acquisition observers?

5.2.2 Learned Patterns

While the data on natural and learned eye movement search patterns are inconclusive some experimental data on learned search techniques for target acquisition are available.

Training in scanning patterns of search probably is effective. Thomas and Caro (1962) evaluated search patterns to be used by Army observers engaged in low altitude, slow speed target acquisition. They report that performance was directly related to the type of search pattern the observers were instructed to use. Head movement directing the line of sight from

the horizon abeam the aircraft inward toward the aircraft and back outward at a fixed rate (side movement method) produced significantly better identification of targets than, in descending order, the forward movement method, the forward fixed method or the side fixed method. In the forward movement method, the observer "looked forward at a 45° angle to the line of flight initially and then swept his gaze back toward the rear of the aircraft". In the forward fixed method the observer looked at the same 45° angle to the line of flight but did not move his head. In the side fixed method, the line of sight was fixed 90° to the line of flight and downward.

The observers in the Thomas and Caro studies were not monitored for head movements during flight; rather, it was assumed that they had in fact, followed their training instructions during the test flights. The consistency of the data indicates that the four groups of observers were using different patterns of search.

Gilmour, as quoted by Snyder (1973), has noted that for nearly all air-to-ground search conditions the observer wastes more than 40 percent of his time in useless search activity during the period after the target has become available but before it is reported as acquired.

Search pattern training should help reduce this wasted time; however, other applications to target acquisition have not been reported (see 5.3.3).

.3 Parameters Affecting Search Efficiency

The target and its surrounding context, the aircraft in which the observer is flying, and the observer himself all interact to affect search performance. The extent and quantitative relationship of these parameter interactions are not well established. Most research has concentrated upon target variables, secondly upon the parameters determined largely by the aircraft and only a small amount upon the observer.

Emphasis upon the target is natural; it is the object of search. Many things about the target can be measured and reported in quantitative relationships that can be used to help predict search performance. The fact that these predictions are only partially effective (see Section 6.2) may mean that more than just the target is involved in target acquisition.

In 1965 through 1968, Joint Task Force Two (JTF-2), under authority of the Joint Chiefs of Staff, began a systematic research program to investigate all aspects of the low-altitude attack mission. One goal of the JTF-2 program was to establish a simulation data base that was validated by large-scale controlled field tests. The initial research studies did help reconcile the large volume of analytical and laboratory data obtained under widely varying and uncorrelated conditions.

In analyzing the results of the real-time target acquisition studies, the major source of variance (62 percent) in visual target acquisition performance was found to be directly attributable to differences between the targets and their associated backgrounds (Wyman, et al, 1968). This variance was, for the most part, unexplained however. The remaining variance

affecting target acquisition performance included aircraft-related and observer performance variability as well as atmospheric effects (Chapter 3).

5.3.1 Target Variables

What things related to the target affect search performance and how are they measured? In some respects the answers to the question depend upon who is asking, and for what purpose.

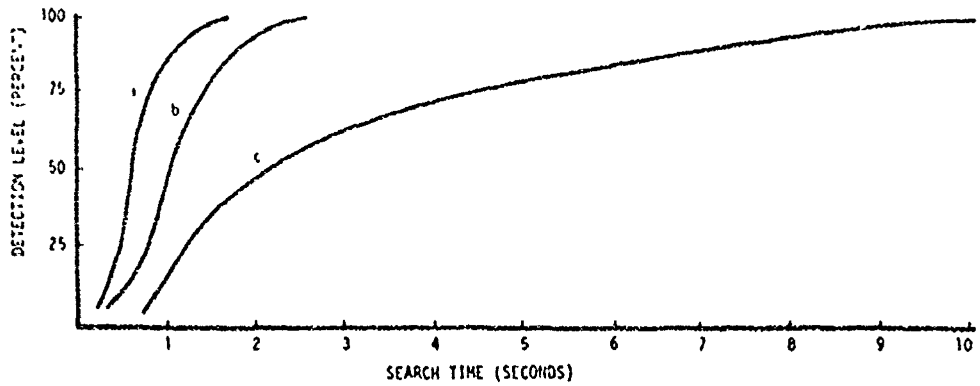
5.3.1.1 Search Time

The typical engineering question is, "How long does it take an observer to search for and find a target?" Two things are involved:

First, is the question, "How long is the target exposed?" Target exposure time is the interval between the time at which the target first becomes available for detection and the time at which it leaves the observer's field of view. This time is a secondary variable largely determined by aircraft speed (V) and altitude (H), slant range to the target, masking effects, and field of view of the observer or sensor. These problems are discussed in previous chapters. The solution is essentially a matter of geometry, the V/H relationships, and some knowledge about the target area. Second, given that the target is actually visible, how long does it take an observer to acquire a target? The answer to this question is much more complex.

Bloomfield (1970) has reviewed the laboratory data on time to search. He points out that density of non-targets similar in size and shape to the target (clutter), size of the search area, and number of targets are all so related that we cannot separate them in real-world search. Laboratory experiments in visual search can, however, provide parameters which should at least bound the problem and establish the limits for system design. Since the laboratory data on visual search is extensive we will note only those experiments which appear pertinent to the real world target acquisition problem. Many of the laboratory experiments relating to visual search have been limited to search for simple objects in relatively unstructured fields. (For a review and analysis of this research see Teichner, 1972; Teichner and Krebs, 1970; 1971; 1972a; 1972b; and Teichner and Mocharnuk, 1974). The target acquisition problem is more frequently that of searching for complex shaped objects in very cluttered visual fields. The laboratory data indicate that key variables are target size, shape, contrast, density of non-targets, search area and target location in the search area.

In general, time to search is exponentially distributed (Krendel and Wodinsky, 1960; Bloomfield, 1972), as shown in Figure 5-3. The parameters of the exponential term depend on the relative complexity of the targets and of the area to be searched.



SOURCE: REDRAWN FROM BLOOMFIELD (1970)

Figure 5-3. Search Time. Curves a, b, and c indicate increasing relative complexity of background.

Relative to the background, large or high contrast targets are found faster than small or low contrast targets (Boynton and Bush, 1957; Smith, 1961); see Figure 5-4.

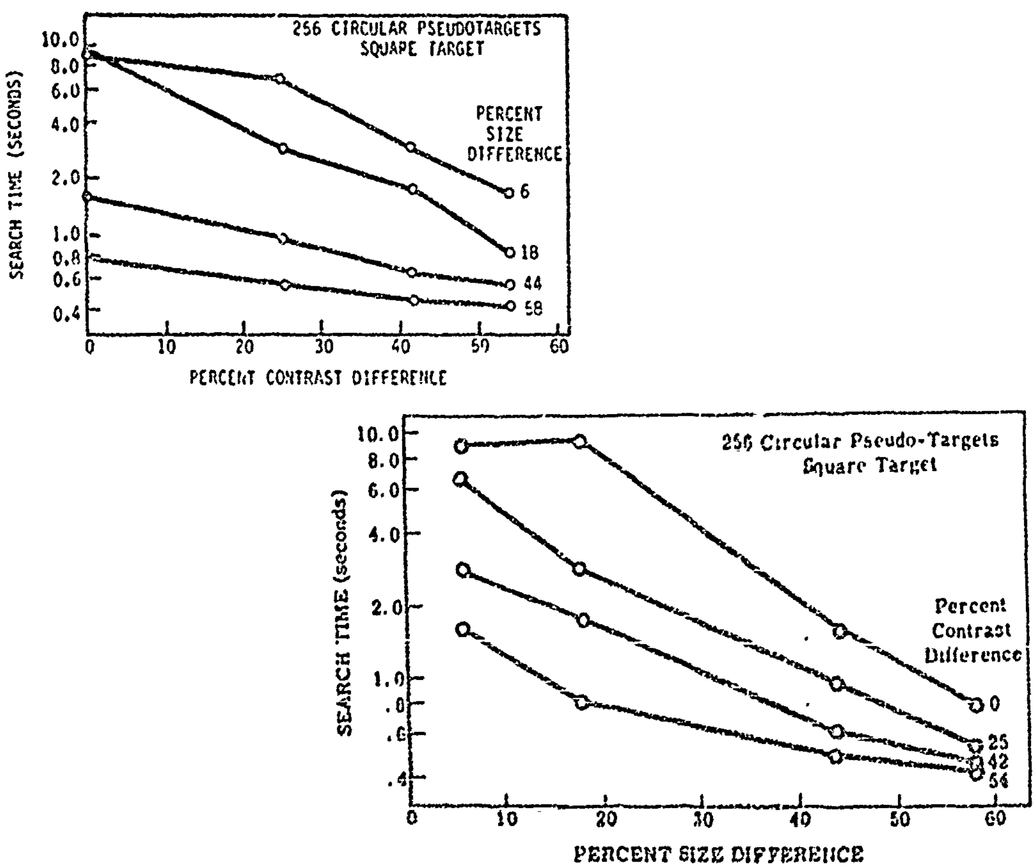
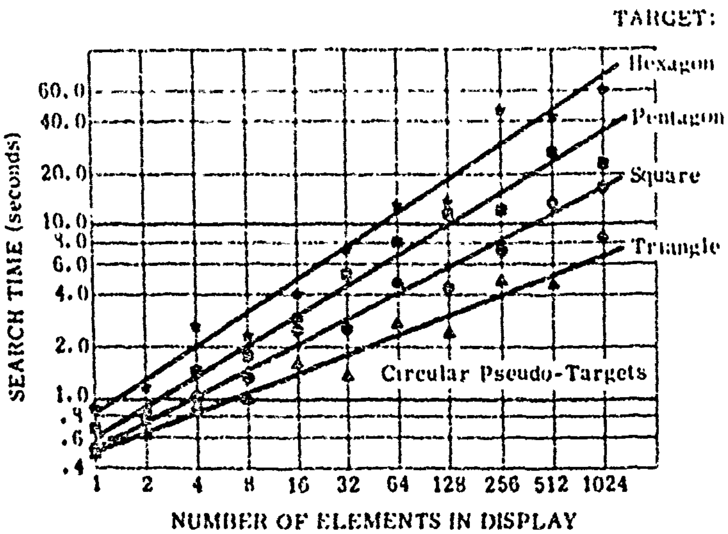


Figure 5-4. Search Time as a Function of Target and Pseudo-Target Size Difference and Contrast Difference

The larger the number of objects in the target area similar to the target in size and/or shape (i.e., "clutter") the longer the search time (Boynton and Bush, 1957; Baker, Morris and Steedman, 1959); see Figure 5-5.



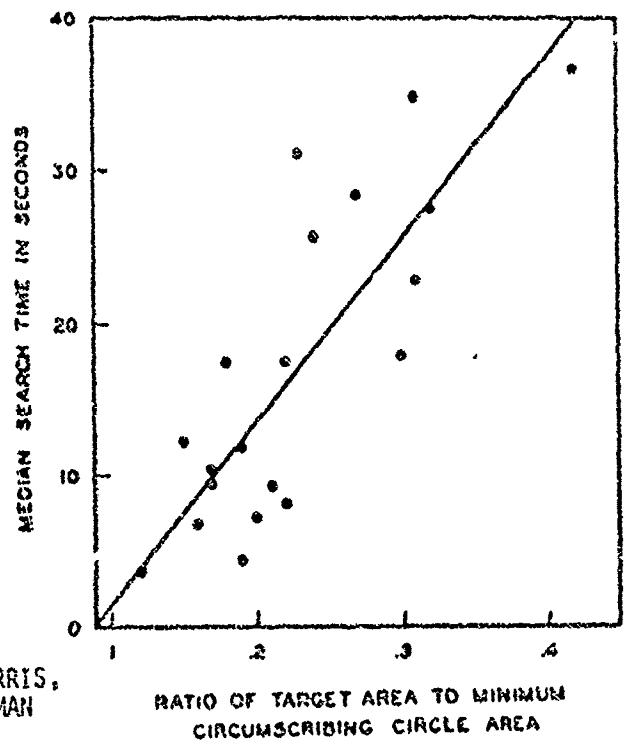
SOURCE: SMITH, IN VISUAL PROBLEMS OF THE ARMED FORCES (1962)

Figure 5-5. Comparison of Results for Triangle, Square, Pentagon, and Hexagon Used as Targets Among Circular Pseudo-Targets

Long narrow objects are usually seen with less error and in less time than square targets of equal area (Baker, Morris and Steedman, 1959); see Figure 5-6.

Within limited search areas (i.e., displays or a restricted cockpit field of view) targets located on the periphery require longer search time than those near the center of the search area (Baker, Morris and Steedman, 1959; Craig, 1974).

Leaving the laboratory, the typical operational question is, "At what range can the observer search for and find the target?" Obviously time to search is involved in the range of target acquisition. The faster the aircraft is flying, the less time the operator will have from the time the target is available to be seen until it is acquired or missed. Target availability is, of course, a function of many conditions and includes - at least - resolution of the eyeball (sensor), unmask range, atmospheric attenuation, contrast, target motion, etc. Target acquisition research has concentrated on range, not time. Typically, even motion picture or terrain model simulation studies report target acquisition as a function of range. Time is not, usually, seen as the critical variable, although in actual fact, range can be converted to time in most situations.

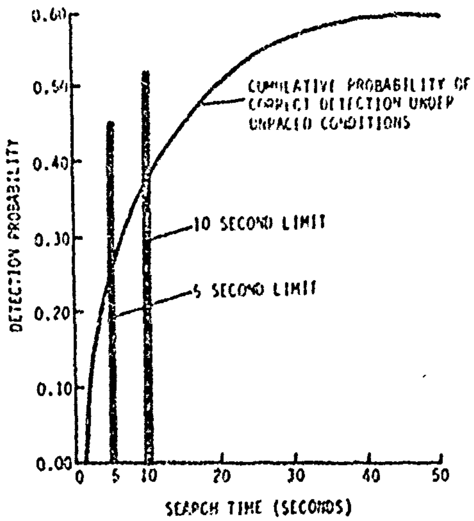


SOURCE:
BAKER, MORRIS,
AND STEEDMAN
(1959)

Figure 5-6. Search Time as a Function of The Ratio of Target Area to the Area of the Minimum Circle Which circumscribes the Target. The correlation is + 0.82 and the function is described as Y = 117 x -10.

There are several studies, however, which have evaluated some of the variables noted as affecting time of search and in which time of search was reported.

In a simulation study using oblique aerial photographs to simulate TV, Parkes (1972) had unskilled observers search under two conditions of limited time, 5 and 10 seconds. The tactical targets were "typical of those expected for the Martel missile". Results of the limited time study were then compared with an earlier study (Parkes, 1972b) done under the same conditions, but with a 50 second limit on search time. Results are shown in Figure 5-7. With less time the acquisition probability was reduced. The decrease in probability was also reported as more marked for small targets than for large ones.

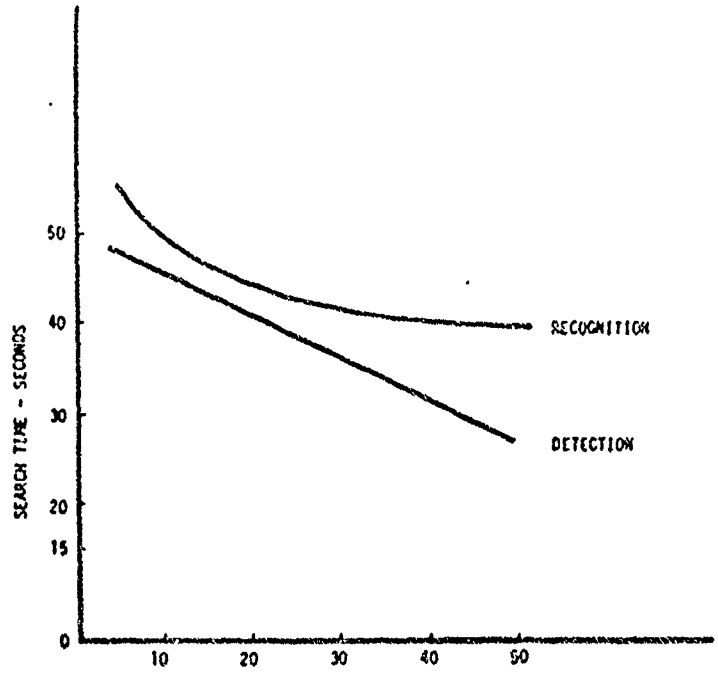


SOURCE: Parkes (1972).

Figure 5-7. Comparison of Performance Under Timed and Untimed Search Conditions

Freitag and Jones (1972) had pre-briefed observers search a television-display of a scale terrain model (Section 6.4.3) for large (or prominent) targets (bridges, road intersections). The objective was to determine minimum times to detect. Mean time to detect varied from 3.7 to 8 seconds. The data are very similar to the results found by Parkes. Long narrow targets were significantly easier to find than were rectangular targets.

One realistic simulation merits discussion since it is one of the few primarily designed to control target contrast and, also where search time is available. Bergert and Fowler (1970a) used the Martin Marietta 600:1 scale terrain model, (Section 6.4.3). Observers searched for a to-scale 37.5 by 18.75 foot flat target of a house or shed using direct vision looking out a simulated A-4 cockpit windscreen. The targets were painted to precisely control target-to-background contrast (measured to ±2 percent). Observers were all ex-pilots (company employees) who had a minimum of 1100 hours military flight experience. Clutter was not a variable. All targets were placed in open areas, not near other buildings or similarly sized objects. Observers were carefully briefed, using both a vertical and oblique aerial photograph which indicated the type of target as located somewhere within a 1/2 mile square area. "Detection" consisted of locating the target in the area; recognition was correctly specifying the target as a shed or a house. The run was conducted at a simulated altitude of 3000 feet (914 meters) and a speed of 350 knots (649 Km/HR). Each trial began at a simulated range of 37,000 feet (11,278 meters), near the minimum resolvable target visual angle, but at which range the area was visible. The trial continued toward the target until the target was recognized or until the minimum downlook angle for the "A-4 cockpit" was reached. Mean time to search, as a function of contrast is shown in Figure 5-8; the data confirm that dynamic target acquisition search time is a function of contrast.



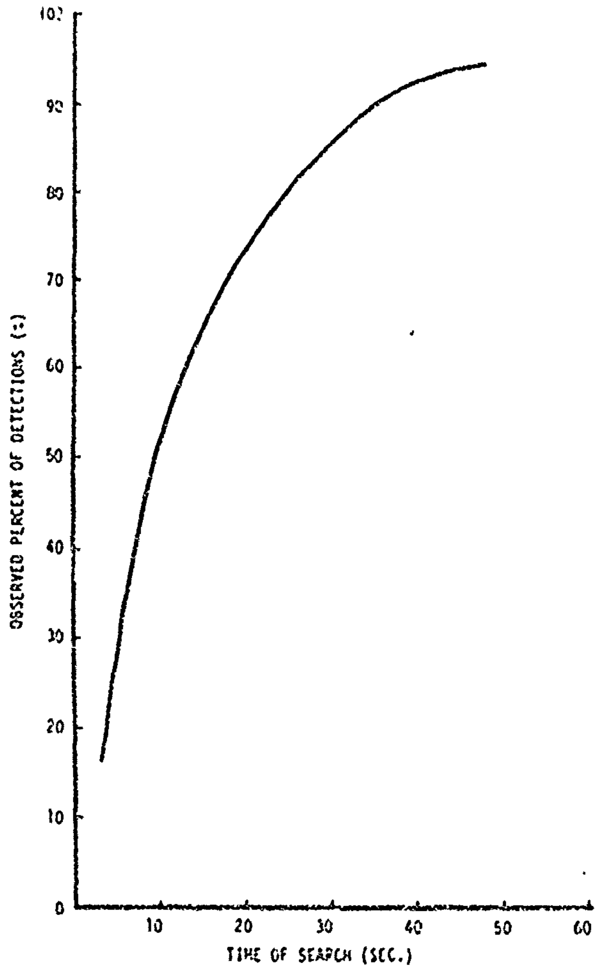
SOURCE: REDRAWN FROM BERGERT AND FOWLER (1970a)

Figure 5-8. Dynamic Flight Simulation - Mean Time to Search a Prebriefed Square Area 1/2 Mile (0.8 Km) Per Size for 37.5 Square Feet (11.4M) Target as a Function of Contrast

One set of field tests with time to search as a measured variable has been summarized by Bryson (1972). A helicopter with pilot and observer used pop-up tactics to search for and locate tactical targets (tanks and armored personnel carriers). The helicopter rose vertically ("popped-up") to gain line of sight with the target. It came to a hover just above mask while the crew searched. The targets were armored vehicles, (tanks and armored personnel carriers), tactically deployed with cover and masking. On command the helicopter "popped-up" above mask and search for the target was begun. The observers were briefed as to approximate location of the targets in relation to their position. Fifty percent of the targets were found in 10 seconds; if a target was not found by 48 seconds, the probability was that it could not be found at all. Figure 5-9 shows these data. (The obtained exponential function is also quite obvious.)

The Bergert and Fowler data represent probable search times for a single target at maximum ranges by one observer under optimum conditions. The data reported by Bryson are for multiple targets, search by two observers at relatively short ranges.

At very low altitudes and high speeds, search-time requirements are different from those at a greater altitude. If the target is not found rather quickly, it may not be found at all.



SOURCE: BASED ON BRYSON (1972) DATA

Figure 5-9. Search Time for Two Briefed Observers to Locate 5 Armored Vehicles

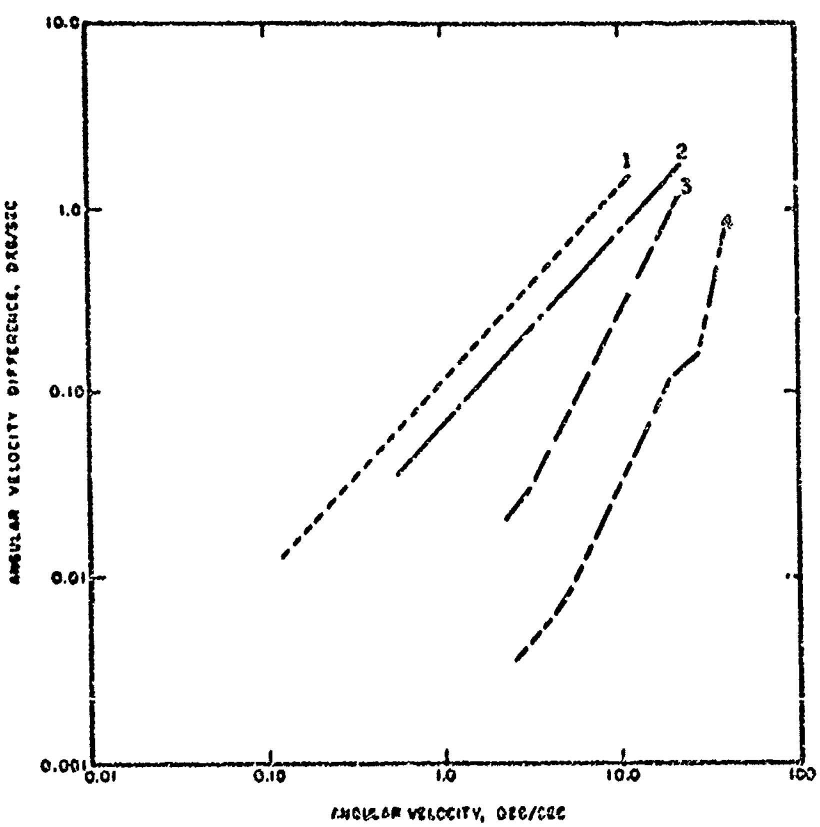
5.3.1.2 Moving Targets

Motion of the target probably enhances detection in one of four ways: (1) a new target is created by the motion as it changes location, as the wake of a ship or a dust cloud behind a tank; (2) the change in location of the target due to its motion is noted; (3) in some cases, the relative motion per se of the target as compared with non-targets attracts the observer's eyes, and (4) the changing contrast of the target moving across the background. When a target is moving in a search field it must move fast enough to be recognized as moving (see Section 3.2.5). Erickson (1965) presents a brief summary of the visual theory involved:

Consider two objects moving parallel through the visual field with angular velocities ω_1 and ω_2. A differential threshold for angular velocity may be defined as $\Delta\omega = \omega_1 - \omega_2$. That is, the difference between the angular velocities of the two objects must be at least $\Delta\omega$ or an observer cannot with any confidence tell that there is a difference.

Laboratory measurements of $\Delta\omega$ have been made with moving spots on an oscilloscope, rotating disks, needle pointers, and other such devices. It has been found that $\Delta\omega$ is a function of the angular velocity of the reference object such that

$W = \frac{\Delta\omega}{\omega}$ = constant ($\omega \neq 0$) within certain limits. W is known as the Weber ratio. From data summarized in Brown (1961) and as shown in Figure 5-10, it is seen that W = 0.14 for curve 1 and W = 0.88 for curve 2.



1. Adjacent stimuli
2. Separate stimuli
3. Superimposed stimuli, 3.6 deg field
4. Superimposed stimuli, 15.0 deg field

SOURCE: BROWN (1961), AS REDRAWN IN ERICKSON (1965)

Figure 5-10. Velocity Discrimination Thresholds

Consider the simple case of a moving target being viewed from an aircraft flying level with constant velocity. If the target is moving along the ground track of the aircraft, its angular velocity would be:

$$\omega_T = -\frac{(V-v)H}{H^2+R^2}$$

where V = velocity of aircraft
v = velocity of target
H = altitude of aircraft
R = range ahead to target

as compared to the angular velocity of points on the ground about the target, which is given by:

$$\omega_g = -\frac{HV}{H^2+R^2}$$

It can be shown that:

$$W = \frac{v}{V}.$$

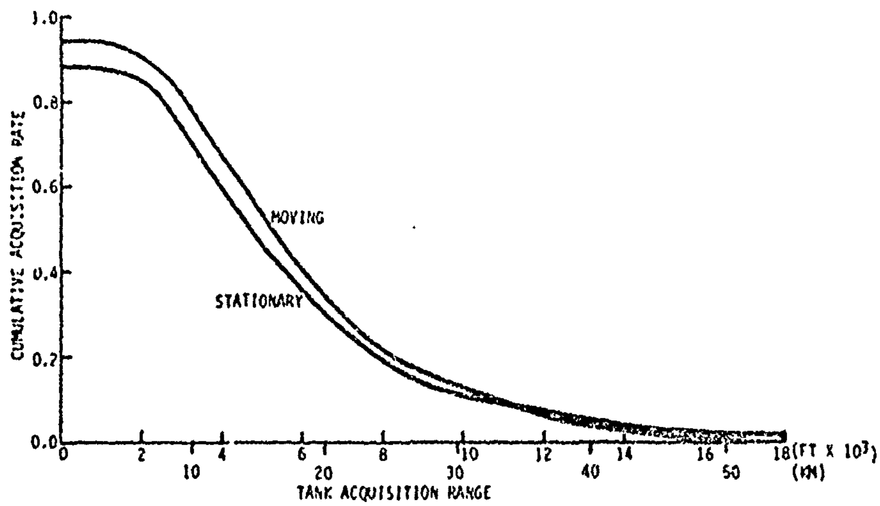
If a Weber ratio could be determined for the above situation and were found to be 0.10, say, it could be concluded that targets moving less than one-tenth the aircraft's velocity would not be spotted by virtue of their motion per se.

In most cases of high speed flight (above 350 knots or 649 Km/HR) typical tactical targets moving at 10 to 30 mph (19 to 56 Km/HR) should not have enough relative motion to be detected as moving from high performance aircraft. Yet field test data do show some improvement in target acquisition with moving targets.

A series of controlled field tests indicated that moving vehicle targets - a truck, a tank, and a group of trucks - tended to be acquired at slightly greater ranges than when the same targets were stationary (Valentino, 1972). The rate of travel of the vehicles, 20 miles (32 Km) per hour, was such that their relative motion compared to aircraft at the speeds (300 and 450 knots or 556 and 834 Km/Hr) and altitudes flown was probably below the visual threshold of motion. Yet the moving targets were generally acquired at greater slant ranges. Figure 5-11 shows typical results.

A study by Dugas (1971) also helps explain the probable effects of relative target motion. Her experiment compared the detection probability between a static and a moving target on a television display. Backgrounds were, (1) an aerial photograph displayed at a scale of 5000 feet (1524 meters) altitude, (2) a felt plate of uniform texture and brightness, and (3) a gridded table. The target was an electronically generated rectangle of uniform intensity. Two target speeds, corresponding to about 50 and 200 knots (93 and 371 Km/Hr) were used. The faster moving target was detected more easily than the slow one and both more easily than the static target against

all backgrounds. Data obtained indicate that "it is not motion itself that improves detection performance, but the changing contrasts that occur as the target moves over a complex background,"(Dugas, 1971, p. v).



SOURCE: VALENTINE, 1972

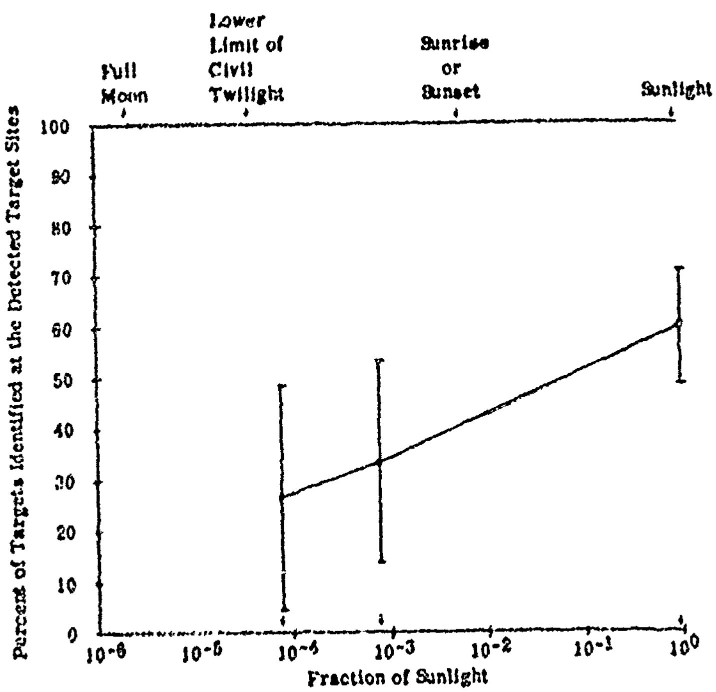
Figure 5-11. Cumulative Acquisition Rates as a Function of Slant Range and Target Motion

5.3.1.3 Surround Illumination

For all practical purposes, once illumination level reaches about 100 foot-lamberts (342.6 cd/m^2)(an overcast day), performance in target acquisition search should not be affected (Duntley, 1964). The field test data support this contention (Hicks and Moler, 1966; Snyder, et al, 1966). Cloud cover, so long as it does not obscure the target does not seem to have much effect. Dyer (1965) and Whittenburg (1960a) both report that high cloud cover actually was a help in target search (additional illumination data are discussed in Chapter 3).

However, when illumination level drops below a critical level, such as at twilight, then visual target search performance drops dramatically. The study reported by Porterfield, et al (1971) provides clear evidence. This study investigated inflight visual detection of ground target sites and identification of specific targets as a function of apparent scene illumination. Individuals from three groups of six subjects each searched for tactical target sites in rolling farm and woodland, and identified and counted the targets at the sites located. One group observed under full sunlight illumination, a second group wore goggles with neutral density filters that cut down the transmitted light so that the scene appeared to be illuminated by 400 times full moonlight (4.3 meter candles) and a third group wore goggles that reduced the sunlight illumination level down to an apparent illumination of 40 times full moonlight (0.43 meter candles).

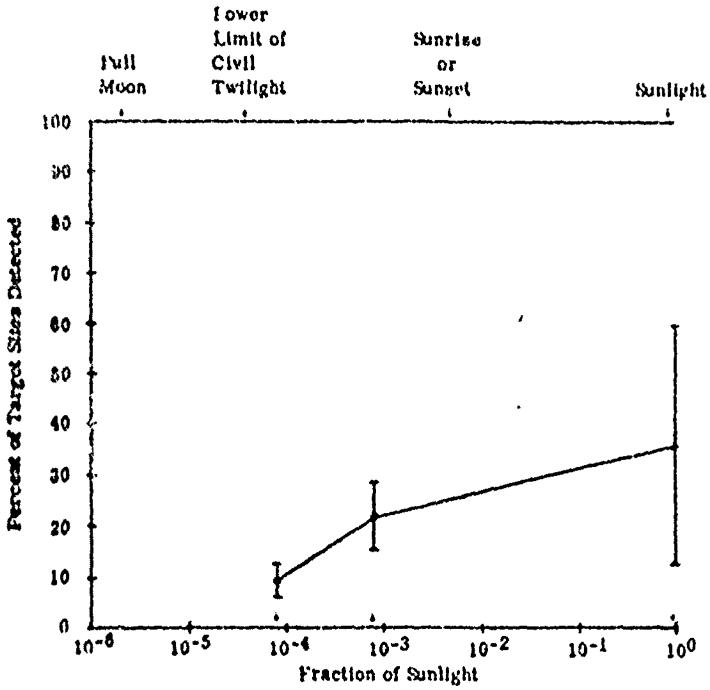
The apparent scene illumination for both the groups that wore goggles was between that of the lower limit of civil twilight and sunrise or sunset. The subjects observed from the nose position of a B-50 flying at 180 knots (334 Km/HR) ground speed and 3,500 feet (1067 meters) above ground level. There were 25 target sites at various locations, all within two miles (3.2 Km) of the aircraft flight-path, along the 96-mile (154 Km) track-length. Each site contained various numbers and types of simulated tactical targets. The mean number of target sites detected was 36 percent under sunlight illumination, 22 percent under the simulated 400 times full moonlight condition, and 9 percent under 40 times full moonlight. The mean of the targets identified, provided they were detected, was 60 percent under sunlight, 34 percent under 400 times full moonlight, and 27 percent under 40 times full moonlight. Figures 5-12 and 5-13 show the results.



	$8x10^{-5}$	$8x10^{-4}$		1
Mean	26.7	33.6		59.9
Standard Deviation	22.0	19.8		11.1

SOURCE: PORTERFIELD, ET AL. (1971)

Figure 5-12. Percent of Targets Identified at the Detected Target Sites as a Function of Illumination Level



	8×10^{-5}	8×10^{-4}		1
Mean	9.4	21.9		36.0
Standard Deviation	3.1	6.5		23.5

SOURCE: PORTERFIELD, ET AL. (1971)

Figure 5-13. Percent of Target Sites Detected as a Function of Illumination Level

5.3.1.4 Target-Background Relationships

A different approach to defining and evaluating target variables has been proposed by Zaitzeff (1971). He believes that in actual real-world conditions it is nearly impossible to separate the variables of target from background. Bloomfield, as noted earlier in this section, makes the same assertion. Thus, Zaitzeff proposes a different type of target-background metric to be used in the prediction of dynamic visual target acquisition.

A study was conducted using a series of wide-angle photographic slides taken from JTF-2, Test 4.1 simulation studies (Zaitzeff, 1971). Ten targets were selected; for each target 10 slides were prepared. The initial

slide was at the maximum available range (target just visible but no detail resolvable). The other nine slides each represented a progressive one-tenth reduction of this range into the target. These characteristic target-background scenes were then measured using two approaches - one using subjective ratings scaled by observers, and the other being physical and photometric (size, contrast, brightness) measurements. JTF-2 simulator target acquisition data were also available. Fourteen measures of targets and background characteristics, plus an estimate of target acquisition probability were obtained for each of the 100 scenes. Factor analysis showed that many of the variables investigated were highly correlated. Ridge regression, a technique applicable to non-orthogonal problems, was used to establish the relative predicting power and quantitative effect of these variables.(1)

Of the 14 variables tested, 7 basic parameters were isolated. These parameters were: (1) Target Length, (2) Target Width, (3) Detail Contrast, (4) Target Contrast, (5) Element Count, (6) Ambiguity, and (7) Heterogeneity. These parameters accounted for 79 percent of the criteria variance. The same amount of predictive information was obtained using a measure of static acquisition probability - - the percentage of 16 observers designating the target in each of the 10 scenes of the approach to a target. Static acquisition probability is not necessarily operationally useful, since it requires a large number of ratings by a reasonably large group of observers (see Section 6.3.9, for an application of these data).

Zaitzeff suggests that some techniques of psychometric scaling could be used to develop target-background metrics more closely related to dynamic performance than those physical measures noted above. The characteristics he recommends are:

<u>Distinctiveness</u> - the degree to which an item specified is a unique, one-of-a-kind appearing element.

<u>Conspicuity</u> - the degree to which an item stands out from the background because of its size, shape, color or structure. A conspicuous element would usually be in marked contrast to other items within the field.

<u>Embeddedness</u> - the degree to which an item appears enmeshed with or indistinct with reference to the contrast elements around it. A target with high embeddedness generally cannot be pinpointed accurately because it is in juxtaposition with elements or areas of like contrast.

<u>Localizability</u> - the relative proximity of an item to an outstanding or conspicuous cue, or to the dynamic flight vector.

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(1) See Box and Hunter (1956) for a discussion of ridge regression.

Expectation Value - the degree to which a scene corresponds or appears similar to the observer's preconceived ideas of the target approach. The observer's expectations would be based on his briefing, inflight information, psychological set, and experience.

Busyness - the degree to which the background in question exhibits the property of being a patternless collection of contrasts.

If the above variables can be quantified (probably through the techniques of psychometric scaling), a large step will have been taken in establishing a useful classification scheme for operational target-background encounters. This task remains to be done.

5.3.2 Aircraft Variables

Since the aircraft is a moving platform, motion is a factor which must be considered. There are three possible conditions of movement involved in air-to-ground target search:

a. Movement of the observer through a relatively static environment. This is the usual condition of flying over an area to search for a target.

b. Movement of the target relative to the environment and the observer. This is the condition when a vehicle or ship is in motion through the target scene.

c. Movement of the background and the target relative to the observer. This condition occurs when the observer is viewing a TV scene of an area over which he is flying or when monitoring the TV scene projected from a remotely piloted vehicle (RPV) or a missile.

The effects of movement in search are not well understood. The general conduct of air-to-ground search while in aerial flight is so obviously a case of motion of the observer through the scene (condition a.) that we rarely take time to consider it. The second motion condition has already been discussed (5.3.1). Finally, the increased use of electro-optical displays has made imperative our need for a better understanding of the problem of relative motion through and by the display.

5.3.2.1 Speed

The general case in air-to-ground search is: Does aircraft speed make a difference in visual search? The problem also becomes confounded with time and altitude. As we move faster we have less relative time to search and, as we decrease in altitude, relative angular velocity increases. We consider speed, time, and altitude separate variables, although the three are in fact very much related.

Thus, although this discussion concerns only the dynamic effects of relative motion, it is recognized that time is very much involved in the actual search problem. As noted in Chapter 2, Figure 2-8, dynamic visual acuity varies as a function of angular velocity from the observer. One obvious characteristic of the visual field as seen from the aircraft is apparent angular velocity as the environment streams past the moving aircraft. Observers tend to compensate for high angular velocity by fixation on an object in the visual scene for some time period, and then jumping ahead to fixate on the next area. While flying at low levels and at relatively high speeds, this is the recommended technique (see "Pilots Panel" in Jones, 1972b).

The observer who flies at medium (about 1500 feet or 457 meters) to high altitudes should find angular velocity no problem during target search. Dugas (1962) analyzed the problem of high-speed, low-altitude flight. Her conclusion is that the human visual system does not limit visual target search at high aircraft speeds except at altitudes below 1500 feet (457 meters). The data support this conclusion (see also Section 2.3.5).

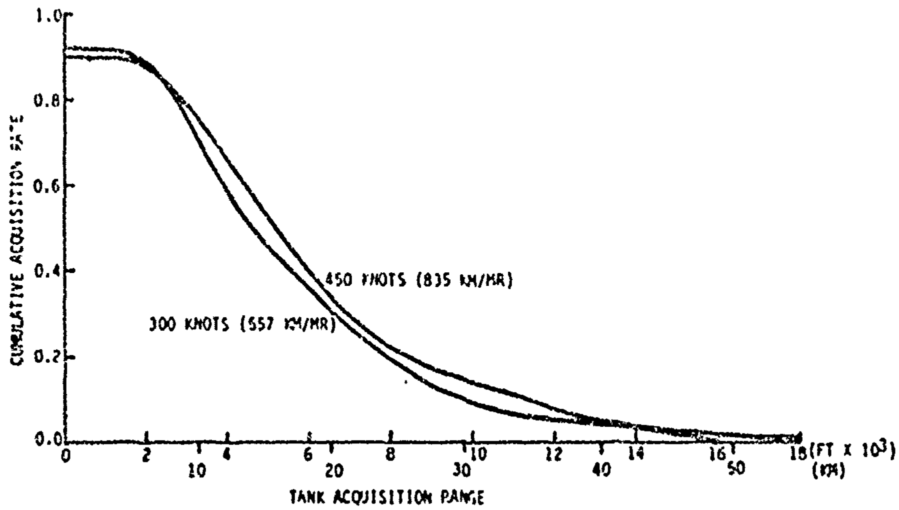
U. S. Air Force tests of target search conducted at altitudes from 200 to 1500 feet (61 to 457 meters) and at indicated aircraft speeds from 350 to 720 knots (649 to 1334 Km/Hr) report no significant problems in detecting targets at those speeds and low altitudes (Thackham, Wade and Clay, 1966).

Dyer (1964) reports that in flight trials carried out at an altitude of 500 feet (152 meters) there was no significant effect on acquisition probability as a result of increasing airspeed from 350 knots to 700 knots (649 to 1334 Km/Hr). However, the mean acquisition range at the 700 knots (1297 Km/Hr) speed (11,250 feet) was less than those for the 550 knots and 350 knots (1019 and 649 Km/Hr) speeds (15,200 feet or 3429 meters) and 16,300 feet (4968 meters) respectively, although the differences were not statistically significant.

Valentine (1972) found in field tests using F-105 pilots slight but not significant differences in cumulative acquisition ranges at speeds of 300 and 450 knots (556 and 834 Km/Hr) as shown in Figure 5-14.

Motion picture simulations report similar results. At an altitude of 500 feet (152 meters), performance was better, in terms of both acquisition probability and acquisition range, at a speed of 198 knots (367 Km/Hr) than at 594 knots (1100 Km/Hr)(Calhoun and Snyder, 1965), or at 792 knots (1468 Km/Hr)(Rusis and Calhoun, 1965). Jones, Lane and Gilmour (1967) report that at 500 foot (152 meters) altitude single observer acquisition probability was significantly poorer at a speed of Mach 1.2 than at either Mach 0.4 or Mach 0.8, but there was little change in mean acquisition range. Two observer teams had small improvement in acquisition range with decrease in speed.

Low speed (40 to 100 knots)(or 74 to 185.3 Km/Hr) low altitude (up to 500 feet - 152 meters) tests of U. S. Army fixed wing and helicopter aircraft indicate a small decrement in target acquisition with increasing speed (Blakeslee, 1963; Thomas, 1965).



SOURCE: VALENTINE, 1972

Figure 5-14. Cumulative Acquisition Rates as a Function of Slant Range and Airspeed

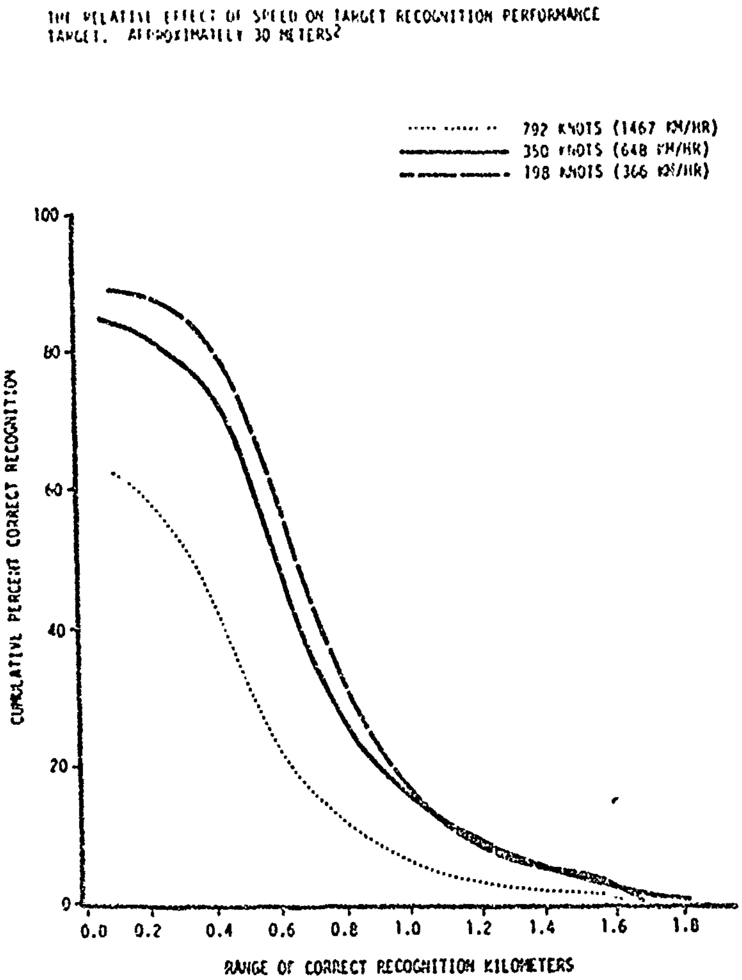
Speed, at least in the regimes typical of current tactical aircraft, is not a significant variable. What does seem to be important is that higher speed reduces time to search. Figure 5-15 indicates generally the relative effects of speed based upon simulator data at low altitudes.

5.3.2.2 Movement of the Background and the Target

Typically, target acquisition by use of dynamic electro-optical (EO) displays can present a visual field which moves both background and target relative to the observer. Viewing a moving scene is normal for TV and motion pictures. When the scene itself moves in a way different from the relative personal orientation of the observer confusion can exist. This is the condition of "scene rotation", considered in more detail in Section 4.2.13. The condition is a relatively new one in target acquisition research. Data from both Freitag and MacLeod (1974) and Price (1974) indicate that scene rotation does not much change expected target detection ranges. It does, however, significantly reduce range of target recognition. More investigation and research is required.

5.3.2.3 Altitude

The effect of altitude on target acquisition is confounded by other variables. Increase in aircraft altitude affects the visual environment to facilitate finding targets in some cases, but also to reduce it in others. Obviously at some high altitude, targets of interest will be too small to see. The biggest effect of altitude change occurs from 0 to 1500 feet (457 meters). The relative importance of altitude depends largely on the mission and on tactical requirements. The factors involved are:



SOURCE: REDRAWN FROM RUSIS AND CALHOUN (1965), AND FOWLER AND JONES (1971)

Figure 5-15. Relative Effect of Speed on Target Recognition Based on Simulator Data

a. An increase in altitude increases the amount of terrain that can be seen and thus increases possible cues available.

b. Reduction of the effects of masking.

c. Change in apparent size and shape of the target. When the target is viewed from above, an increase in altitude changes the visual angle at the observer's eye; but the extent and direction of that change depends on the shape of the target. If the vertical scale predominates it will seem smaller. If the horizontal area predominates, it will seem larger. Thus,

a vertical chimney will seem smaller, an air field will appear larger. Details of the target thus seem to change significantly as our aspect angle changes.

d. Reduction of rate of apparent motion of the terrain through the observer's field of view, as noted in Section 5.3.1.2.

e. There is, relatively, an increase in visibility downward through the atmosphere to the target (see Chapter 3). The appearance of a target viewed from a given distance vertically downwards will be less affected by attenuation effects than one viewed obliquely from the same distance.

The combined effects of these factors mean that there is usually an optimum altitude for a particular type target and set of conditions. Above and below this altitude there may be degradation in target acquisition.

The most commonly found result is that performance tends to improve almost linearly as altitude increases up to some maximum. A field test reported by Dyer (1965) found that recognition ranges for vehicles and other tactical targets at 200 feet (61 meters) altitude were less than half those obtained at 500 feet to 1500 feet (152 to 457 meters). The probability of detection was also slightly greater at higher altitudes. Valentine (1972) reports similar results, typically shown in Figure 5-16.

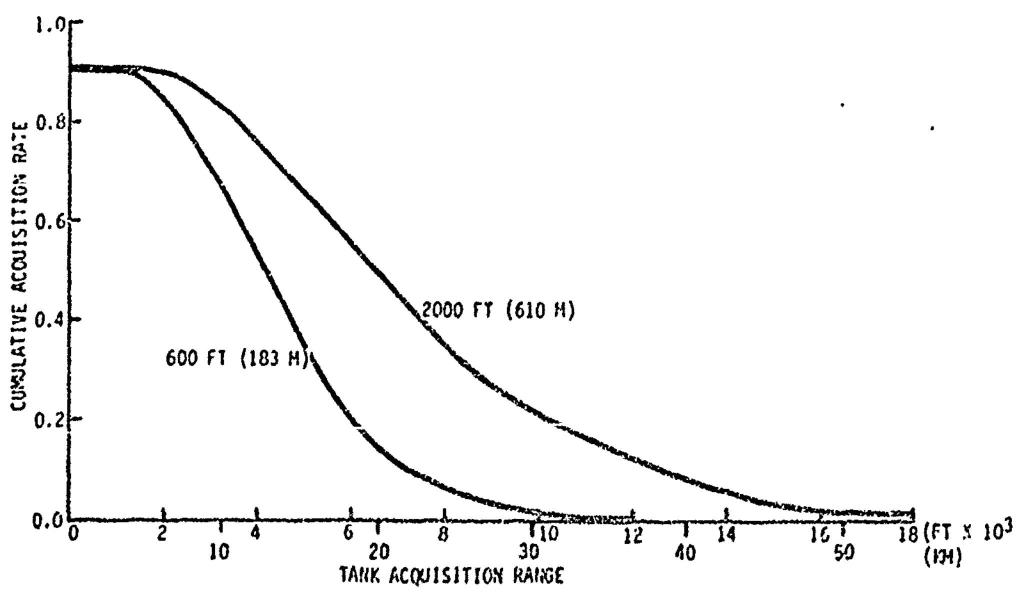
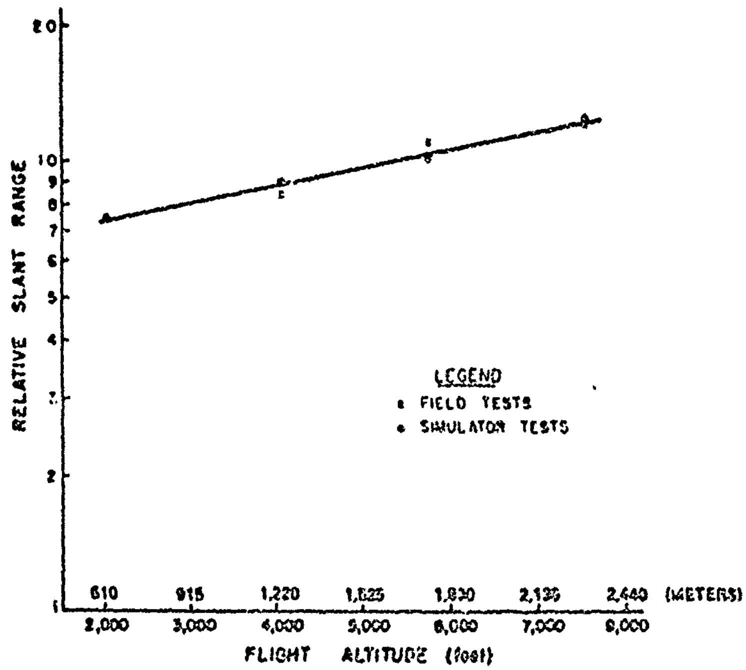


Figure 5-16. Cumulative Acquisition Rates as a Function of Slant Range and Aircraft Altitude

Results obtained from simulation experiments show similar trends. For instance, using a terrain model and four types of homogeneous background, Wyman, Rawlings and Sturm (1965) found that altitude had a significant effect on both the probability and range of acquisition, increases in altitude from 300 (91 m) to 500 (152 m) and to 1000 (305 m) feet resulted in better performance. Blackwell, Ohmart and Harcum (1960) report similar results in Figure 5-17. Using a motion picture simulator, Gilmour and Iuliano (1964) found increased acquisition from altitudes of 200 to 400 feet (61 to 122 meters). Similar data are reported by Snyder, et al (1966) at altitudes of 500 feet (152 m) and 1000 feet (305 m); by Wyman, et al (1967) at altitudes of 200 to 600 feet (61 to 183 meters) and by Gilmour, et al (1968), with the Joint Task Force Two Motion Picture Program, at altitudes of 200, 400, and 600 feet (61, 122 and 183 meters) using wide-angle motion picture imagery.



SOURCE: BLACKWELL, OHMART AND HARCUM (1960)

Figure 5-17. Relative Slant Range as A Function of Flight Altitude, Showing a Systematic Change in Slant Range with Altitude

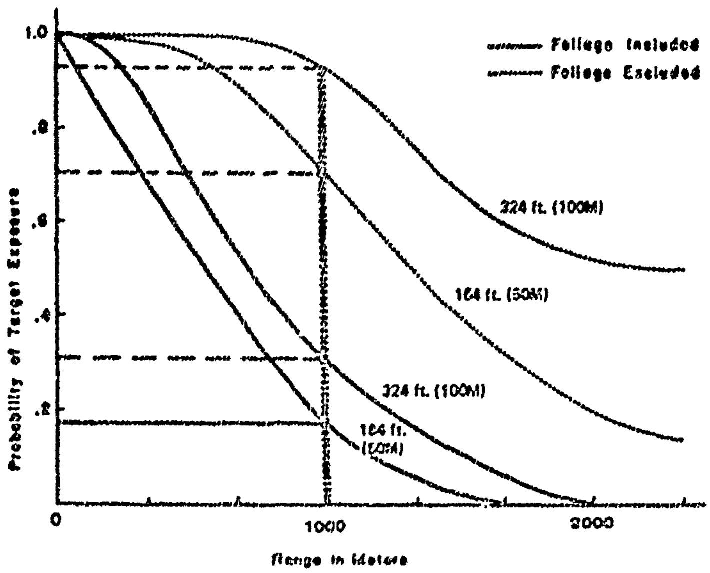
Erickson and Gordon (1970) reported a field test which most clearly shows the effects of altitude. The targets were a tank and a radar van placed on a road in the desert both facing directly head-on to the aircraft flight path. Search for the target was simple, no clutter or masking existed, and there was little or no weather effect. The pilots flying in A-4 aircraft reported "Detection" (vehicle present) and "Recognition" (tank or van). Recognition performance increased with altitudes up to 4000 feet (1219 meters).

There is, of course, a limit beyond which increase in altitude will reduce performance. Target acquisition performance will exhibit a maximum with altitude and show a cut-off at a slant range beyond which the target cannot be seen. That maximum depends upon several variables and includes at least target size and apparent contrast as seen through the atmosphere, as does the optimum altitude for visual target acquisition. Boynton hypothesizes that "under the best conditions of visibility it (optimum altitude) is on the order of 250 times the linear size of the objects being sought; under conditions of worst visibility it is on the order of 30 times the size of the object being sought" (in Morris and Horne, 1959; page 238). This hypothesis has not been field tested, but comparison with field test results (Erickson and Gordon, 1970; Valentine, 1972; Thornton, et al, 1973) shows that it holds up rather well. Valentine for example reports that personnel could not be reliably detected at 2000 feet (610 meters) altitude, but were acquired at the 600 feet (183 meters) altitude test condition.

Very low and slow flying aircraft (typically helicopters) present a different problem. At altitudes above about 500 feet (152 meters) there probably is little difference from fixed wing aircraft. However, the advantage of the low-flying helicopter is its ability to stay low, using the masking of terrain and trees as cover. Thus, reported target acquisition ranges for very low-flying aircraft confound altitude with target masking. When the target can be seen and it is unmasked, it often can be acquired at long ranges. Snyder, Greening and Calhoun (1964) report a significantly higher probability of target recognition at 50 feet (15.2 m) altitude than at 100 feet (30.5 m) wherever the targets were unmasked. Apparently this is because the aspect angle of the target at very low altitudes is very much like the way we normally perceive the world. Nap-of-the-earth flying (5 to 10 feet (1.5 to 3.1 m) by helicopters, however, emphasizes masking of both the aircraft and the target. The effects of masking are such as to significantly confound low altitude target-search. Unfortunately, few if any low altitude studies have reported detailed data on masking effects.

Moler (1962) conducted a study of low-level target acquisition from helicopters the results of which are typical of most subsequent helicopter studies. The targets were all tactically positioned and camouflaged. The pilots were instructed to fly low altitude (less than 100 feet (30.5 meters)) contour flying over rolling terrain with good tree and brush cover. Only minimum briefing was used. Detection data indicate low probability of finding targets. Maximum range of detection for tanks was 1400 yards (1280 meters); median range was 300 yards (274 meters). Given detection, recognition probabilities were very high, a fact not surprising in view of the short range of detection. Since Moler reported no data on masking, his results are often discounted. However, a series of target acquisition tests using observers in helicopters was conducted at the Naval Weapons Center (Amundson, Schlanta and Sorrenson, 1974). The nominal altitude was 150 feet (46 meters). The ranges reported, however, were only slightly longer than those found by Moler, 347 meters for a tank.

Enderwick, et al. (1970) report a study using a helicopter in target acquisition with tanks and personnel carriers as targets. Flight altitudes were 75, 1000, and 3000 feet (23, 305 and 914 meters). There was little or no masking of targets since the targets were located in open fields in most cases, and all targets were well briefed. Mean target recognition slant ranges at 75 feet (23 meters) altitude were 1130 meters; at 1000 feet (305 meters) altitude, 2610 meters; and at 3000 feet (914 meters) altitude, 3940 meters. No detection probability data are given. Typical very low altitude target acquisition probability is shown in Figure 5-18.



SOURCE: U.S. Army (1974)

Figure 5-18. Average Probability that a 7-Foot (2.15 Meters) Target is Exposed as a Function of Range and Altitude with Foliage Included and Excluded (redrawn from Ballistic Analysis Laboratory, 1959). Altitude is shown on each curve.

5.3.2.4 Target Offset

Lateral offset of the target from the line of flight has not often been reported or considered as a variable. However, in many aircraft, visibility is often not as good straight ahead as off to the side. Inadvertent offsets can also occur whenever the lateral position of the aircraft is not known due to navigation errors or other uncertainties.

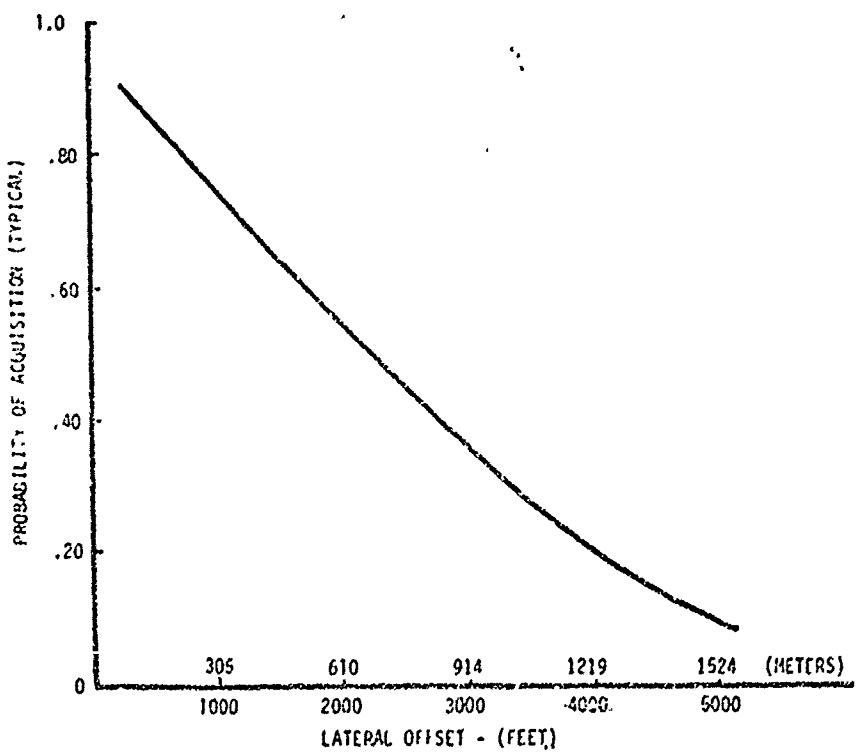
Several studies have simulated with TV on terrain models the effects of lateral offset uncertainty on search performance (Levy et al, 1964). One field study has also investigated offset and position as controlled variables (JTF-2, 1966). Since the reports of this study are classified,

details are not made available here. In general the results show that target acquisition performance decreases with increasing lateral offset from the primary flight path of the aircraft.

In a training research study using helicopters and light aircraft, Thomas and Caro (1962) considered target offset from the flight path as one condition in training tests. Their data also indicate offset from the pre-planned flight path reduces performance in the same way.

Wyman, Rawlings, and Sturm (1965) found that offsets of 500 and 1500 feet (152 and 457 meters) reduced probability of target detection, but not the range of detection. A simulator study carried out by Milnes-Walker, as reported in Parkes (1972a) indicated that offsets from 0 to 800 to 1600 meters did not reduce absolute target detection range for vehicles, but did reduce the probability of detection.

Figure 5-19 shows the general effect on probability of target detection for tactical targets as a function of offset.



SOURCE: REDRAWN FROM WYMAN, RAWLINGS AND STURM (1965). MILNES-WALKER (1970). PARKES (1972a)

Figure 5-19. Probability of Target Acquisition as a Function of Lateral Offset-Typical Data from Simulation Studies

5.3.2.5 Vibration

An excellent review of the general effects of vibration is that of Grether (1971). A review of the effects of vibration on visual acuity has also been published by Snyder (1965). Vibration impairs visual acuity, and is at a maximum at about 10-25 Hz. In most cockpit situations it can be alleviated by head restraint. "The more complex intellectual tasks, target identification and monitoring, show no decrements related to vibration". (Grether, 1971, p. 210).

5.3.2.6 Type of Aircraft

Visibility toward the ground will vary significantly with the type of aircraft (Kennedy and McKechnie, 1970). The inherent geometry of the cockpit, location of the cockpit in relation to wings, engine nacelles and other obstructions obviously can make a difference in what can be seen. Design requirements for fighter aircraft require a minimum 11 degrees over the nose visual depression angle (MIL-STD-850). Kennedy and McKechnie (1970) present visibility data on several typical aircraft and describe a useful technique for determining visibility from several types of aircraft.

Often the aircraft type is not well suited for the search role assigned it. Under these conditions the observers try to adapt to that situation. For example, data reported by Erickson and Gordon (1970) indicate that some A-4 pilots may have rolled over to observe since some of the pilots reported recognition ranges at locations which should have been masked from the aircraft cockpit. Looke (in Jones, 1972b) also reports that when using a high performance aircraft in a low-level target search role it was routine to conduct the mission flying upside-down. Where there are significant inherent aircraft visibility differences, then that aircraft with the best visibility should be a prime candidate for a search mission.

5.3.2.7 Crew Size

A number of experiments have been carried [illegible] determine whether two crew members, carrying out a target acquisit[illegible] [illegible]ask as a team, perform better than a single crew member.

The effects of crew composition were studied by Zaitzeff, Jones and Jahns (1966), using motion picture simulation of low-level flight, during target acquisition performance for large, fixed targets by single observers and by two-man teams. They found that teams of two observers acquired the targets at significantly greater ranges than single observers, on average 24 percent greater on the first pass and 15 percent greater on the second pass. The teams also missed fewer targets.

Similar results were found using small tactical targets, except that at the fastest speed tested, Mach 1.2, the acquisition ranges of the two-man teams were not significantly different from those of single observers,

(Jones, Lane and Gilmour, 1967). Crew workload was not a factor; however, Zaitzeff (1969) reported that when realistic flight workload tasks were imposed on the crew, two-man crews acquired targets at 30 percent greater ranges than one-man crews. The improved capability of the two-man crew seems to result from simply doubling the number of searchers looking at the same area.

5.3.2.8 Observer Seat Position

Does it make any difference where the observer sits in relation to the pilot? A study by Porterfield, et al (1971) investigated airborne visual reconnaissance from the nose versus side-looking stations of a B-50 aircraft. Six subjects performed the search task at the nose station and six different subjects performed the task at the two side-looking stations, located aft of the wings. The aircraft flew at 180 knots (334 Km/Hr) groundspeed and at 3500 feet (1067 meters) above ground level. A mean of 65 percent of the target sites was detected by the subjects in the two side stations, whereas only 36 percent were detected by the subjects in the nose station. On the other hand, for the target sites that were detected, the subjects stationed on the side identified only 37 percent of the individual targets while the subjects in the nose identified 60 percent. There is no explanation given for this latter difference in identification. It may be that the nose station allows the observer more time to study the target after deteccion, i.e., he was able to detect the target earlier in time.

Seat position in helicopters made some differences in a recent field test reported by Amundson, et al, 1974. The observations from the left seat position of the OH-58 were found to be better at absolute range of target acquisition (719 meters) than from either the front (534 meters) or back (631 meters) seat of the AH-1C. The observers estimated ranges better from both seat positions of the AH-1G than from the left seat of the OH-58.

5.3.3 Observer Variables

What characteristics of the observer affect his visual search and target acquisition performance? While a variety of possible observer variables have been suggested, the practical number is more limited. Visual acuity for example must be a factor, but the careful selection process used for pilots and observers will obviously eliminate those without a minimum satisfactory acuity level. Intelligence may be important if the general population were included but operational requirements tend to limit selections and further training should reduce any initial differences. Parkes (1972a) reports that intelligence was related to target acquisition performance in naive subjects, but not in experienced observers. The data from a wide spectrum of studies do indicate that observers vary over wide ranges in measured performance while engaged in search for targets.

In the reported simulation and field studies, the observers were usually either military pilots or male college students with measured normal vision. Only a very few of these simulation and field studies

have varied observer characteristics in a controlled way. Some of the laboratory search studies have considered observer variables, although in these studies the subjects have also usually been college students. Thus, most observers have been selected from a restricted population. In general target acquisition observers are male, of above average intelligence, and carefully selected for good eyesight, physical condition and probably are well motivated. Research reported by Seale (1972) indicates that there are no significant measured personality differences that affect target acquisition performance.

5.3.3.1 Experience and Training

Search performance should improve with experience. The results are not as conclusive as we might expect, however.

a. Practice on a Search Task - Laboratory data when searching complex displays generally show improved performance with practice. Baker, Morris and Steedman (1959) used a series of shapes with several complexity levels in a visually projected set of imagery. They found a considerable improvement in mean time to detect and a reduction in errors with practice. Figure 5-20 shows the effects of continued practice on search performance. This is in line with the expectation that the more complex a visual task the more likely it is that practice would lead to improvements. Parkes (1967a) found that skilled, experienced observers did better in a simulated camouflage search task. Experience seems to help even in simple visual acuity tests. Taylor (1964) undertook a prolonged investigation wherein subjects detected a disc of positive contrast presented in the center of a uniform background for exposures of 0.33 second. He reports a rapid improvement in the average threshold level over the first five sessions, and a much smaller but consistent improvement from the fifth to the fiftieth session. Taylor recommends that a correction factor of 1.90 be used to increase the laboratory-type search task times of experienced subjects to correct for that experience.

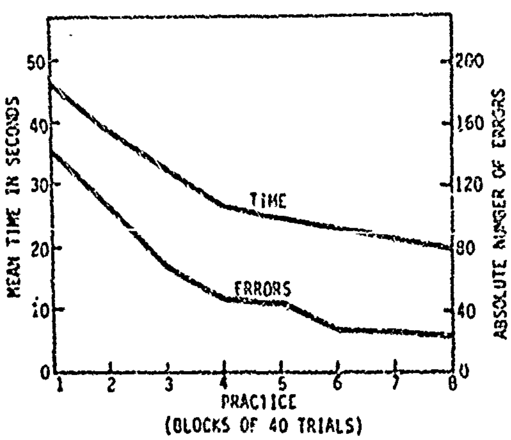


Figure 5-20. Performance as a Function of Practice. Each practice point represents 40 target recognitions per subject. Each point on the curve was derived from 1280 observations.

SOURCE: BAKER, MORRIS AND STEEDMAN (1959)

Thus, in the more complex situations of target acquisition search, one might expect to find similar practice effects.

b. General Experience - In a simple search task Erickson (1966) found no performance differences between 12 high school boys and 22 Navy pilots. A simulator study reported by King and Fowler (1972) found no differences in performance on a television target identification task between college students and experienced pilots.

Gilmour (1965) in a motion picture simulation used three classes of observers: (1) non-pilots, (2) pilots on their first exposure to targets, and (3) pilots on second exposure. The non-pilots made more errors and achieved shorter target acquisition ranges than the pilots. The only statistically significant difference, however, was between non-pilots and pilots on second exposure. Since the non-pilots did not receive two exposures, direct comparison of their learning ability is not possible.

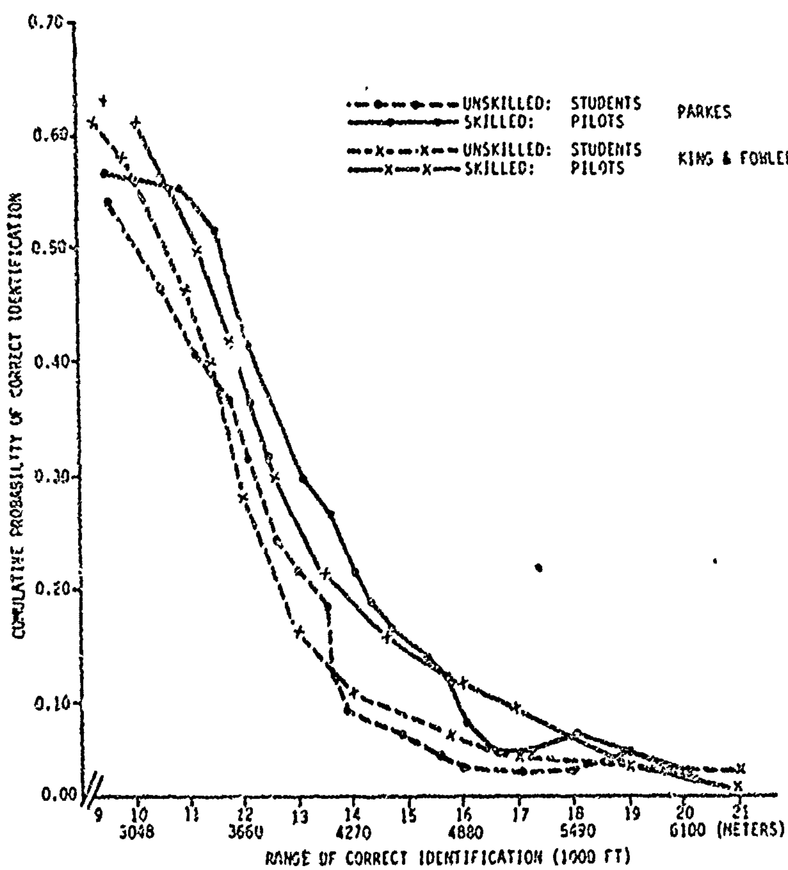
A film simulation by Rusis, et al (1965) compared experienced pilots with non-pilots. In this study, it was found that there were no significant differences in percentage of targets recognized or in recognition range between the two groups. The opposite result was found by Parkes and Rennocks (1971) using television simulation. In this case acquisition probabilities were not significantly different for the two groups, but skilled subjects tended to report longer acquisition ranges with less variance. A similar result was found by King and Fowler (1972) using a TV simulation; experienced pilots were not significantly different than college students, but the pilots were less variable in performance.

Little controlled field-test data are available. Results reported by Whittenburg, et al (1959b) were obtained from flight trials in which experienced and inexperienced aerial observers took part. Their data showed that the experienced observers were more accurate in target identification than the inexperienced observers. Amundson, Schlanta and Sorrenson (1974) report no significant differences in target acquisition from helicopters between groups of trained observers who had from 0 to 2600 hours of combat experience. Figure 5-21 shows the probable variability difference in general target acquisition between skilled and unskilled observers.

c. Specific Search Experience - Although the data indicate that general observer experience does not necessarily mean good target search capability, specific experience and training does seem to improve search performance. Heap (1962) has made a field comparison of first and second runs over a target. On the average, his observers obtained an increased probability of recognition (87 percent to 97 percent) and an increase in recognition range of approximately 3000 feet (914 meters) on their second exposure to the target run.

Simulator experiments in which repeated exposure to a particular flight track has been studied have shown performance improvements over the first four to six runs. Performance then levels out with little or no

further improvement. For instance, Milnes-Walker (1968) found that target recognition performance on the fourth run could not be distinguished from that on any subsequent runs. A further experiment (Hardon and Milnes-Walker, 1969, as reported by Parkes) suggested that the improvement in recognition range over the first four runs was due to learning of the target and its immediate surroundings rather than learning of the route. Amundson, Schlanta and Sorenson (1974) also found that performance of helicopter observers tended to improve on the second flight over the test area.



REDRAWN FROM PARKES, 1972 AND KING AND FOWLER, 1972

Figure 5-21. Target Acquisition Performance of Skilled and Unskilled Subjects

Anecdotal reports from experienced pilots flying target acquisition missions in combat also indicate that specific experience observing in a particular area improves reported performance (Bone, "Pilots Panel", in Jones, 1972b).

The conclusion seems to be that general search performance may improve slightly with observer experience. However, a short time of direct exposure to the specific target search situation is at least as important as several years of general flight experience.

d. Training - Training in specific target acquisition search techniques has proven to be useful. However, reports from pilots flying observer missions in Viet Nam, indicate that little real practical visual search training was applied (Bone and Looke, "Pilots Panel" in Jones, 1972b). Similarly, Hughes (1966) found no differences in target acquisition capabilities between trained, experienced reconnaissance pilots and fighter pilots. A special training course in target acquisition using a tachistoscopic teaching machine also did not improve performance over a group of conventionally trained pilots (Wade, 1964).

Thomas (1964) identified four necessary visual search skill areas for U. S. Army observers: (1) detecting targets by methodical visual search; (2) identifying targets quickly; (3) maintaining geographic orientation; and (4) determining the location of targets. Classroom instruction and practical flight exercises to develop these skills were incorporated into an experimental training course, which was compared in a simulated combat test against conventional Army observer training. Students with only 32 hours of experimental training reached the same measured performance level as did conventionally trained Army aircraft observers.

The experimental course of instruction was prepared for use by unit training officers, as described by Hesson and Thomas (1962) and later developed as a series of programmed texts incorporating verbal material, maps and photographs (Dawkins, 1964). The programmed texts proved as effective as classroom methods in teaching general search skills with the added advantage that training could take place in the field.

Training aircrews to carry out television target acquisition tasks presents particular problems owing to the narrow field of view and the poor quality of the display as compared with a direct view of the outside world. A specialized research program carried out by Hagen, Larue and Ozkaptan (1966) with particular reference to television displays, determined whether detailed training in the effects of perspective geometry would improve the observer's ability to locate target areas. The training consisted primarily of working out a series of target area location problems on statically-simulated TV displays. The results showed that this training, when given in addition to conventional visual search training, significantly improved performance as compared with the conventional training only; the percentage of target areas correctly located being 81 percent as compared with 68 percent with conventional training.

A more detailed comparison of training techniques for visual search of aerial photographs by U. S. Army trainees was reported by Powers, et al (1973). In this study visual search of tactical aerial photographs was the subject of four different training methods in how to search;

geometric pattern scan, tactical content orientation, a speed reading technique, and free search. The tactical content orientation proved to be the most effective method when both time of search and error rates were considered.

A prototype Forward Air Controller (FAC) training program was developed and tested for the Air Force by Raylor, Eschenbrenner and Valverde (1970). The training was specifically oriented toward Southeast Asia problems and emphasized visual content and target background relationships. When compared to an equivalent group who received conventional FAC training the experimentally trained group scored significantly higher on a criterion test developed specifically for this program.

The experiments cited show that improvements in visual target acquisition performance can be achieved by means of suitable training. In view of the increasing demands made on aircrew by higher speeds and the use of sophisticated sensor displays, specialized training should become increasingly important.

5.3.3.2 Expectation

Expectation is defined as what, and/or where the observer presumes the target to be. In classical psychological terms it is similar to the concept of "set". The process of expectation is not measured; it is assumed from the details of experience, training, briefing, and required performance criteria. We have no quantitative measure of expectancy, yet we are certain that it does affect visual search performance. In both simulator and field studies the most logical way to provide "expectancy" information is through use of briefing materials, a subject to be discussed later in this chapter.

Parkes (1972) conducted a study using film simulation in which use of prepared briefing materials was emphasized. The data indicate that targets "expected" to be located at the point in time and space indicated by the briefing, were in fact detected with a higher probability and at shorter times than those not so located.

A TV simulation study for the Condor missile program is reported by Erickson, Hemingway, Craig, and Wagner (1974) where expectation probably influenced the results. Operators "flew" systems with two different inherent navigation accuracies. In the test the same small, near zero cross range error was actually used in each of two test conditions. The reported probability of acquiring was 0.87, with the system expected by the operator to have as much as 5000 feet (1524 meters) cross-range error. For the same experimental conditions but with a system the operator expected to have as large as a 10,000 feet (3048 meters) cross-range error the reported probability of target acquisition was only 0.62.

When we expect to find a target, we have a higher probability of doing so. Amundson, et al (1974) even report that the best single predictor of an individual's performance in target acquisition was the personal expectation that he was good at it.

5.3.3.3 Motivation

There are almost no data which report the effects of motivation in target acquisition. The Condor simulation study reported by Erickson (1974) may be said to include some motivation effect. When the subject did not expect to find a target due to the "known" wide cross range error they may have been less motivated to search for it.

In a laboratory study of visual search Bloomfield (1970) reports the results of training in visual search, using incentive payments (money) to increase performance. With the use of the incentive, search performance was significantly better in time for both response and search than on simple extended practice, with no incentive. However, the false alarm rate also went up, though not by as much as performance improved. The effect of incentive motivation thus was to increase search overall performance, but also to increase error rate. Smith (1961a) also used money incentive in a laboratory search of displays. He penalized errors and paid off for speed and accuracy. The effects of the monetary incentive were not reported in detail, however, those with low performance were paid less than those who were more accurate. Figure 5-22 shows the results of incentive payments for two subjects searching the most complex display used by Bloomfield.

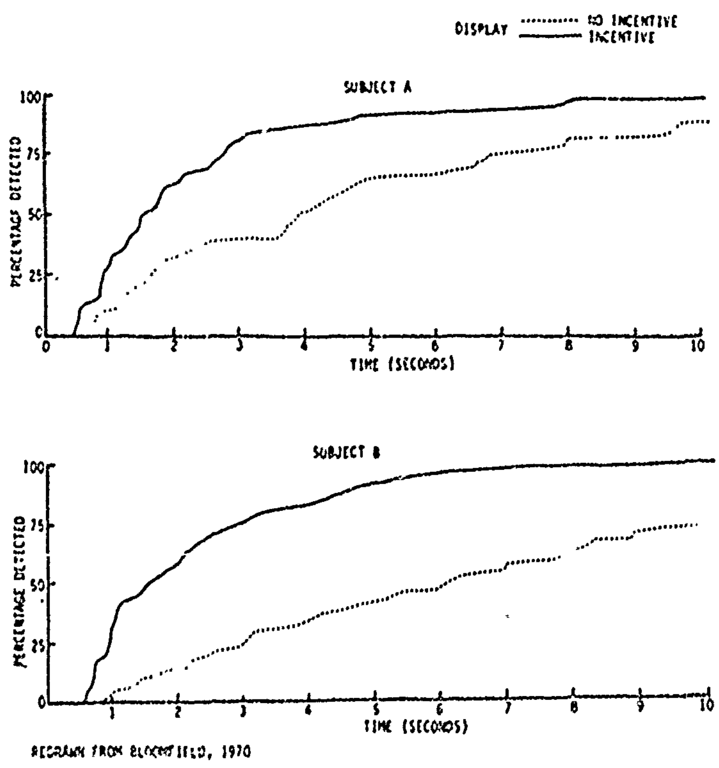


Figure 5-22. Effect of Money Incentive on Search Performance of a Visual Display

Motivation probably helps target acquisition; we do not know by how much, and especially we do not know what the effect is on error rates.

5.3.3.4 Task Loading

Having several competing tasks to perform during a time period is typical of piloting aircraft. In practice an observer (not just the pilot) also usually has more tasks to perform than just to search for targets.

In the vibration study cited (Schohan, et al, 1965) both the pilots and observers had additional duties to perform during the three-hour simulated flight mission. The pilots had a heavier work load than observers. Pilots found 61 percent of available targets while the observers with lower task-loadings found 73 percent of the targets, even though more targets were presented to the observers. Both pilots and observers reported the low-level simulated flight as being subjectively stressful. The difference in search performance between pilot and observer is probably due to the increased task-loading of the pilot.

Dickson (1966) compared search, acquisition and tracking performance in a simulated TV-guided missile delivery when the pilot had tasks other than just missile guidance. He found that the additional tasks degraded performance only when the missile was flown at very low altitude, a more difficult condition of task loading.

Rusis, et al (1965) investigated range and probability of target acquisition with three levels of auxiliary task loading. In this case, the task was to null the error in a meter display in the cockpit by simple, compensatory tracking. Results indicated that there was a small, but significant decrease in recognition range (0.76 to 0.65 nmi - 2.6 to 2.2 Km) and an increase in recognition time (2.4 to 3.2 seconds) when heavy task loading was employed.

Two recent studies investigated target search using television looking at a scale terrain model scene with to-scale military vehicle targets (Freitag and MacLeod, 1973; Price, 1974). In both studies the displayed scene was rotated, simulating changes in sensor line-of-sight. In the study reported by Freitag and MacLeod the operator responded to task load by pushing a button under a panel of lights which were flashed in a random pattern. Observers searched for targets in the displayed rotating scene under conditions of task-loading and no-load. No significant differences in target detection performance were found between the task load and no-load, however recognition ranges tended to be shorter during "task-load". The authors conclude that responding to the lights was not a very complex task, and that it had little task load effect.

Price essentially replicated Freitag's study, but imposed larger measured work loads consisting of required readings of words and numbers on another display while in the process of detecting and recognizing targets. The imposed workloads resulted in improved target acquisition

performance for heavier loads. The fact that improvement rather than degradation of performance occurred was attributed to workloads which were not heavy enough to degrade performance. But significant differences in target acquisition performance existed when the subject was required to change his monitoring strategy by presenting him with information on another display which had to be regarded as of equal importance to that contained in the target scene display. Range-to-target acquisition scores were degraded under this condition compared with similar trials when he monitored the second display at his own choosing.

The results of these studies indicate that imposing light task loading, typical of routine operations, does not appear to significantly impair target acquisition performance. However, when the operational tasks must interfere with the target acquisition task, then performance is degraded.

5.3.3.5 Stress

The search for and the acquisition of targets in actual operational conditions is usually considered to occur under conditions of high task load and stress. The effect of combined stress on target search has not been subject to much research, nor have there been many reported studies of combined environmental stresses on human visual performance (Murray and McCally, 1973). Effects of task loading (a kind of stress) have been investigated as have the effects of some specific physiological stressors:

Temperature - At temperatures of 55°, 75°, and 105°F. (12.8°, 23.9° and 40.5° C.), 24 subjects showed no significant performance change in a simple one-hour target detection-monitoring task, however, small individual differences in detection were reported as being correlated to temperature levels (Arees, 1963).

Noise - Several laboratory studies of simple target detection in the presence of white noise indicate that loud noise (up to 100 decibels SPL) does not significantly affect visual search for targets. Warner (1969) reports that response times to search for and find a simple target on a display of 16 similar targets (random letters), were not different for four levels of noise control, 80, 90, and 100 decibels SPL. However, Warner found the error rate for the 24 subjects to be lower as the noise level increased. Warner and Hemistra (1972) found opposite results using displays of 8, 16, and 32 characters. They report no differences in error rate, but that display complexity was related to performance under noise. With the complex display (32 letters) search performance was better at both the 90 and 100 decibel SPL than at less intense sound levels.

5.3.3.6 Other

Other possible observer variables including age and sex do not appear to significantly affect target acquisition visual search. Within the range of ages usually involved in visual search for target acquisition

(21-45 years), age seems to make no significant difference. (Erickson, 1964a, Erickson, 1966; Johnston, 1965). Sex differences do not affect target identification performance (King and Fowler. 1972; Parkes, 1972).

5.4 Search Aids

There are aids to search which can help the observer. Knowing something about what to look for, when and where to look, and how to look will significantly increase visual capability. Search aids that have been evaluated for use in visual target acquisition include briefing, cues and cueing devices, automatic scanning techniques, and optical aids. Also, as previously noted, training in observation techniques will improve search capability.

Without adequate aids effective visual search is significantly reduced. While the eyeball is the best available all-around sensor for target acquisition, it still helps to know where to look and what to look for. The eye has a relatively small foveal area where most of our fine detailed resolution occurs (Section 2.2). Assured target acquisition performance requires that we place the fovea on the target. This relatively small cone of detailed resolution, about 2° binocularly, requires precision pointing. Help in "where to point" is the function of search aids.

The very real need for aids to search is clearly illustrated in a study of target acquisition reported by Brown (1960). The objective of the study was to develop and verify a method of estimating - - "detection probabilities associated with the process of visually detecting a stationary vehicle from an attack aircraft", (Brown, page 1). As part of the study eight pilots flew one mission each at 1500 feet (457 meters), and one at 5000 feet (1524 meters) altitude. Flight speed in the T-28 aircraft was a nominal 200 knots (371 Km/Hr). This test exercise was equivalent to reconnaissance over unfamiliar territory with no kind of search aid. There was no briefing as to probable targets nor was there even any prior familiarization flight over the area. The only search aid of any kind provided was a map. Each pilot stayed 30 minutes on station, flying a planned route over an Army field exercise area. He was required to fly and navigate the aircraft. When a target was found an umpire in the aircraft rear seat noted its location, that of the aircraft, and the time on a 1:50,000 scale tactical map. The umpire did not participate; he simply recorded. The search area was 144 square miles (373 square meters) of rolling, brown California hills at Hunter Liggett Military Reservation. The targets were approximately 250 U. S. Army vehicles, tanks, and personnel carriers which were present in the area on an Army test exercise. The umpire later verified the pilot's visual sightings by cross-checks with the Army reports of vehicle positions. (The concurrent Army test exercise included accurate vehicle locations as a requirement). The reported probability of detection of a stationary vehicle in the open within 1500 feet (457 meters) to either side of the pilots flight path was 0.15 from the 1500 foot (457 meter) altitude and 0.03 from the 5000 foot (1524 meter) altitude. No targets were detected

at ground ranges of over 2000 yards (1829 meters). Surface visibility was reported to be 30 miles (48.3 Km) on each of the flying days. Finally, the Navy pilots had from 3 to 10 years experience in attack squadrons and five were Korean War veterans.

Clearly, without search aids target acquisition suffers. This section considers the ways in which search for and acquisition of targets can be aided. These include prebriefing, use of cues to aid search, use of extra-observer devices as aids, and use of vision-supplementary techniques such as binoculars.

5.4.1 Pre-briefing

The traditional, most used, and in many ways most useful aid to search is a thorough briefing about the target and target area. Adequate briefing provides two kinds of information. First, information about the area in which the target is located, the terrain and related complexity in which the target may be hidden. Thus, it reduces the uncertainty about where to look. Second, it provides more specific information about what to look for. The standard form of briefing aid for target acquisition is a map or chart. Aerial photographs which give a more realistic view, either vertical or oblique, are also often used. Verbal descriptions of the targets and the target area are typically part of the briefing process as is any other intelligence information available. As illustrated in the cited report by Brown, with no briefing about probable targets and no details about the area of search, the probability of target acquisition is low. That being the case, what kinds of briefing materials are effective?

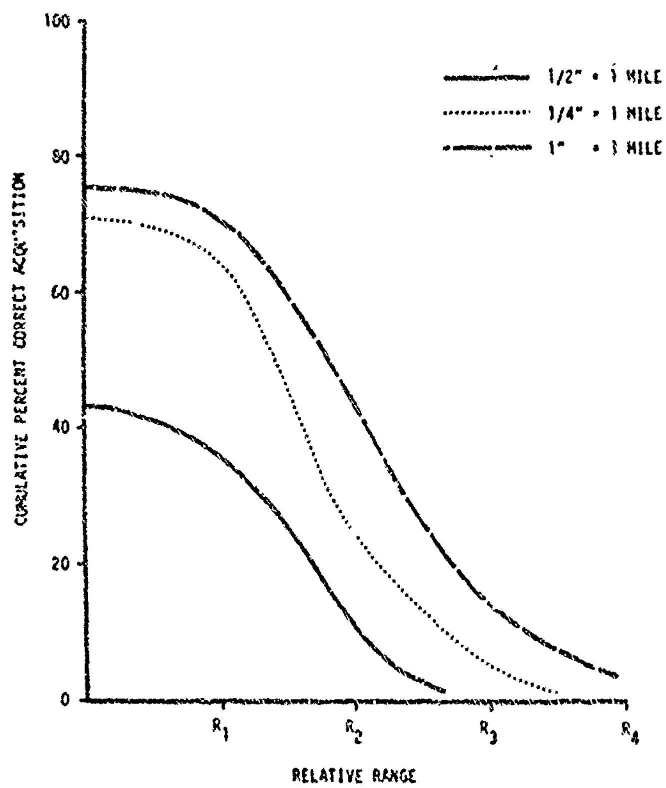
Maps are used both for navigation to the target area and for more detailed target acquisition.

The detailed subject of navigation is beyond the scope of this source book. There is an excellent review of navigation maps and techniques in "Aeronautical Charts and Map Displays", JANAIR Symposium Report, edited by McGrath (1966). Note, however, that navigational uncertainty can indeed cause the target to be missed. McGrath reports that navigational check-point average location errors are typically 1.5 nautical miles (2.8 Km) and tend to increase as distance from the initial point increases. This could mean that the target area is missed; at best it may mean an offset from the planned route of attack. McGrath (1969) reports a JTF-2 study which showed that pilots who were properly oriented on the final target run made fewer errors and acquired targets at longer ranges than those not geographically oriented. When using maps (or any other briefing materials) for target acquisition briefing we must recognize the probability of navigational uncertainty.

While the use of maps as navigational aids has been well investigated there are few data on the most effective maps for target acquisition purposes. If a map is practical for visual navigation it is usually assumed that it will also be useful for target acquisition. However,

visual navigation depends upon the use of prominent check-points which are also easily identified on the map. Targets are usually smaller and more difficult to locate. An effective navigation briefing may not be effective for target acquisition.

Heap (1966a) reports field test data showing that both navigation and target acquisition performance are improved by increasing map scale from 1/4, and 1/2 inch per mile to 1 inch = 1 mile. Figure 5-23, taken from Parkes (1972), shows this relative improvement in target acquisition.



SOURCE: HEAP (1966) AS QUOTED IN PARKES (1972)

Figure 5-23. The Effect of Map Scale on Target Acquisition Performance

However, a study of TV target acquisition reported by Parkes (1972) using naive subjects showed that, in general, addition of a section of 1 inch = 1 mile map covering the final approach to the target, to the standard 1/4 inch = 1 mile route map did not improve target acquisition performance. The only significant difference found was that the proportion of targets correctly identified at a range of 10,000 feet (3048 meters), just before the targets left the lower edge of the display, was higher when the 1 inch = 1 mile maps were also used. The artificial lower limit of 10,000 feet (3048 meters) range may have influenced the

results; the larger scale is useful only at closer ranges. Naive subjects could also be presumed to be less skilled at map reading than experienced pilots.

Photographs, either vertical or oblique are useful briefing materials. More detail is shown than on a map, even one of relatively large scale. They also show textures and tones which cannot be represented on a map. However, the very great detail provided by aerial photograph can be confusing in some cases. (Thomas, 1962). Increasing detail does not necessarily improve target acquisition performance. For example at a recent symposium (Meister, 1974) R. G. Johnson reported that using color aerial photographs (in Viet Nam operations) as an aid to target acquisition was very disappointing. (No quantitative data were provided).

Oblique photographs are valuable as briefing aids. Perspective and masking, not shown on verticals, are accurately represented. The view of the target shown in a forward oblique photograph depends critically on the altitude and axis from which it is taken. Differences in altitude and depression angle result in changes in the apparent perspective. Different position of features appearing within the field of view, and in apparent spatial relationship to the target, may also be confusing. Where practical, the oblique photograph should be as nearly like the attack position as possible.

Thomas, (1964) as cited in Greening and Snyder (1967), made an investigation using vertical photographs of real terrain viewed through a TV with a four inch (10.2 cm) or two inch (5.08 cm) lens, which was approaching the photograph at a simulated speed of 1000 feet (304.8 meters)/second. The task was target recognition only. The results permit some comparison between situations in which the briefing photograph was at the same scale as the test imagery or at a different scale, and also the situation in which a 1:50,000 scale topographic map was used instead of a photograph for briefing. The results are shown in Table 5-I. These results (for a very special condition) indicate that the more nearly like the actual situation the briefing can be the better will be performance.

TABLE 5-I

Recognition Performance vs. Briefing Material Characteristics

	4-in (10.2 cm) TV Lens		2-in (5.08 cm) TV Lens		
Briefing:	Photo Same Scale	Photo Diff. Scale	Photo Same	Photo Different	Map
Recognition time (sec)	36.4	59.9	54.1	61.8	68.3
Altitude at recognition (Thousand ft)	59.6 (18.2 m)	36.1 (11 m)	41.9 (12.8 m)	34.2 (10.4 m)	27.7 (8.4 m)
Errors/per Trials	1/24	4/24	4/24	7/24	10/24

Rusis and Rawlings (1966) report a laboratory study using motion picture simulation to determine the effects of five different operational types of briefing information upon air-to-ground target recognition performance. The five types were as follows:

Type I - (a) Ground-track map
(b) 500 ft. (152 meters) altitude oblique target photos
(c) 1000 ft (305 meters) altitude vertical target photos.

Type II - (a) Ground-track map
(b) 500 ft. (152 m) altitude oblique target photos.

Type III - (a) Ground-track map
(b) 1000 ft (305 m) altitude vertical target photos
(c) Notes from pre-mission briefing on a 10,000 ft (3048 m) altitude strip mosaic showing vertical view of the ground track.

Type IV - (a) Ground-track map
(b) 1000 ft (305 m) altitude vertical target photos.

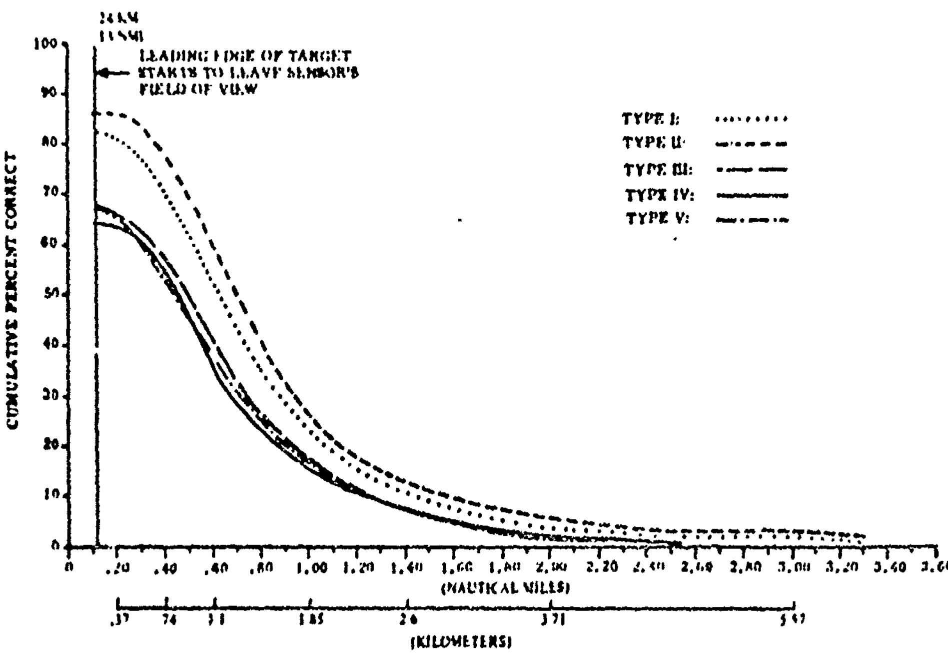
Type V - (a) Ground-track map
(b) Notes from pre-mission briefing on written descriptions of the targets.

Thirty subjects (6 per each type briefing) viewed motion pictures recorded on a flight from Los Angeles to Bakersfield and return; thirty fixed targets were used, typically large (reservoir, airport) and medium (a bridge, overpass) in size. The results are shown in Figure 5-24; clearly the first two types of briefing were more effective. This conclusion is supported by statistical analysis which showed Type II to be significantly better in all but one of the several measures of response used; in that one measure - percent errors - the Type I briefing was slightly better. The results of this experiment indicate that the best briefing for target recognition purposes is that which approximates most closely the imagery actually viewed by the pilot during his mission, i.e., oblique photographs.

The results also varied as a function of specific targets. Some targets were recognized by all subjects under all experimental conditions. Here performance was affected by variables such as target size, target "prominence", or target-to-background contrast. In other words, the "easy to find" targets were reported under all briefing types. Briefing by oblique photos was especially useful for the hard to find targets.

A study using motion picture simulation reported by Jahns (1969) also indicates that briefing with photos is especially useful in aiding rapid acquisition of conspicuous isolated targets. For those targets embedded in complex backgrounds the effects are less spectacular; here the

requirement is for more detailed information about the background to enable the observer to make maximum use of contextual relationships. The oblique photograph proved to be especially useful as an indicator of target context.



SOURCE: ELMS AND RAWLINGS (1964)

Figure 5-24. Cumulative Percent Recognition as a Function of Range for the Reconnaissance/Intelligence Conditions

Parkes (1972) investigated effects of briefing on TV target acquisition using simulation. Her data reported in the 1972 AGARD symposium also indicated that the more closely the briefing information resembles the actual target and surrounding area the more effective it is. Four different types of briefing materials were used: (1) maps only, (2) an oblique to-scale line diagram of the target area, (3) an oblique to-scale line drawing, (4) oblique photographs of the target area. The oblique line diagram and line drawing were sketched freehand based solely on information available from a 1:62,500 scale map. The drawing was oriented in the same direction to the target as the simulated aircraft line of approach. Two oblique photos were used, one slightly off set from the target. Seven experimental briefing conditions were evaluated with six experienced Royal Air Force pilots assigned to each briefing condition. All subjects were allowed as much time as necessary to study the briefing materials, typically 5-10 minutes. The target was a road junction. Briefing conditions and general results for each condition are as shown in Table 5-II.

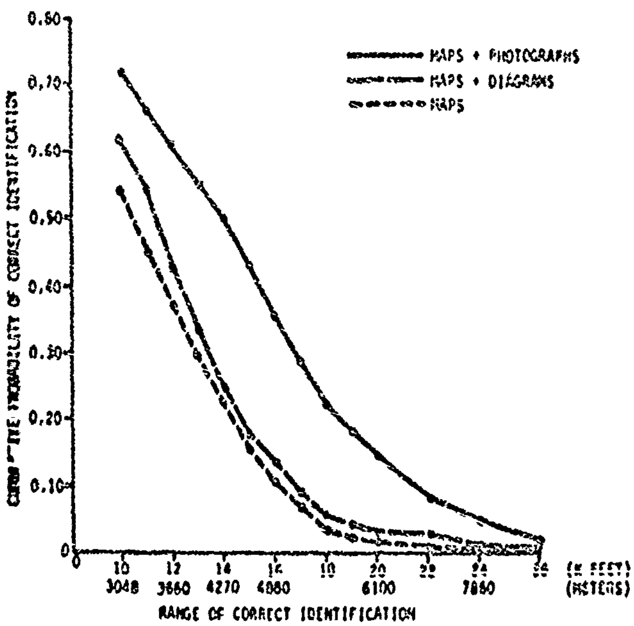
TABLE 5-11

Comparison of Briefing Aid Effectiveness on TV Target Acquisition Using Simulation

Briefing Condition	Probability Correct Identification	Probability Commissive Error
(1) Route map only	0.55	0.20
(2) Route map, plus 1 inch: 1 mile map section	0.50	0.20
(3) Route map plus 1/4 inch: 1 mile diagram	0.61	0.18
(4) Route map plus 1 inch: 1 mile diagram	0.65	0.25
(5) Route map plus map section plus 1 inch:1 mile diagram	0.60	0.19
(6) Route map plus "off set" photo	0.76	0.19
(7) Route map plus "on-track" photo	0.68	0.18
(Route Map Scale: 1/4 inch: 1 mile)		

SOURCE: PARKES, 1972b

Statistical comparisons showed that conditions (6) and (7)(photos) were significantly better than the map briefings, (1) and (2). Use of the photo, (6) was also better than the diagram, (5); and the diagram (4) was better than the maps (2). The photograph, diagram, and map conditions were combined and the results are as shown in Figure 5-25.



SOURCE: PARKES, 1972b

Figure 5-25. The Effect of Briefing on Target Acquisition Performance

Parkes' results suffer from one limitation however: the visual simulation ceased at 10,000 feet (3048 meters) range. This may mean that the larger scale maps would not be as useful. The detail inherent in them may not be as obvious as would be the case at a shorter range. For the tactical situation which was being simulated, release of a missile outside a nominal 10,000 foot (3048 meter) range, her data are useful however.

Classified field test results from Joint Task Force 2, Volume 7 also indicate that the best briefing information is that which most nearly duplicates the scene as viewed by the observer. The more we know about the target area and the specific target the better target acquisition performance is likely to be.

An investigation of briefing techniques was conducted as part of the JTF-2 simulation series of studies (JTF-2, Test 4.1, 1968), as reported by Bliss, 1974. Seven briefing levels were investigated.

Briefing level No. 1, which was the lowest level of briefing specificity, consisted of a designation of areas to be searched for specific kinds of verbally described target categories. This was the only target information provided. The pilots were, in addition, provided with 1:500,000 scale aeronautical charts on which was marked the corridor they were to fly. Conspicuous checkpoints were available and, presumably, the flight paths indicated all went directly across the targets. At this briefing level, for the 12 targets flown against, the target acquisition probability was 0.58 and the average target acquisition range was 6,400 ft (1951 meters).

Briefing level No. 2 consisted of a much more detailed verbal, written, and map presentation. Exact target position information (that is, geographical location) was provided and detailed flight planning information was available to the pilots. At this briefing level the target acquisition probability was 0.68 and the average range at target acquisition was 7,700 ft (2347 meters).

At briefing level No. 3 all of the level 2 information plus high-altitude vertical photographs of the target and its immediate surroundings were provided. At this level the probability of target acquisition was 0.74 and the average range at target acquisition was 7,000 ft (2134 meters).

Briefing level No. 4 included all of the level 2 information provided, plus low-altitude forward obliques of the target area (presumably taken from the correct azimuth to the target). Target acquisition probability was 0.78 and target acquisition average range was 8,400 ft. (2560 meters).

Briefing level No. 5 provided all of the materials of levels 2, 3, and 4. This was the "standard" briefing and was the briefing level used in the actual flight test program. Here the target acquisition probability was 0.81 and the average target acquisition range was 8,700 ft (2652 meters).

Briefing level No. 6 involved all of the information from level 5, plus both vertical and oblique mosaics leading in from the final check-points to each target. At this level, probability of target acquisition ·s 0.78 and average range of target acquisition was 9,700 ft (2957 ers).

The final briefing level, No. 7, involved first a level 1 briefing, then a reconnaissance sortie at low level over the targets, and finally a level 6 briefing followed by the target runs. At this final level, probability of target acquisition was 0.82 and average range at target acquisition was 9,900 ft (3018 meters).

The two significant changes in performance as a function of briefing level were in going from level 1 to level 2 and from level 3 to level 4. Level 1 was the minimal briefing and level 2 was a detailed verbal briefing. The difference between levels 3 and 4 was the addition of an oblique photograph at level 4. Differences between levels 2 and 3, which involved the addition of a vertical photograph on top of the detailed verbal briefing, were not impressive.

Target difference accounted for 89 percent of the total performance variation; while briefing accounted for 8 percent of the total performance variation. A part of this target difference was due to differences target availability as a function of ground masking. When the effects of masking were eliminated targets accounted for 66 percent of performance variation and briefing accounted for 26 percent.

5.4.2 Cueing

One very good way to aid visual search for targets is to cue where or when to look. If the observer can place his narrow foveal cone of high-resolution vision precisely on a probable target area and keep it there for a few seconds inspection then the probability of target acquisition rapidly rises. For our purposes a cue is simply a means of directing the observer's attention toward a specific location and, in some cases, at a certain time. Two general types of cues exist, (1) those that occur in the natural context of the target or target area, and, (2) those provided by some type of automatic aid using the total target acquisition and attack system. Natural occurring cues are the subject of this section. Target acquisition system techniques will be discussed in the next section.

Nearly all of target acquisition research has operated on the assumption that the observer was searching for, and reacting to, the target as defined by the briefing material and procedures. However, it is evident that when an observer is searching for a bridge he is only partly behaving as an image-matching device. He also carries with him considerable knowledge of the nature of bridges. His searching for a railroad bridge across a river will obviously be concentrated in river valleys and will not involve a random or systematic scanning of the entire terrain. He expects to find a bridge over a river at the intersection of the river and a railroad. River and railroad then become cues

for this mission. If briefing materials are prepared with a knowledge of what cues are useful, and thus emphasize what cues are to be expected, better target acquisition performance should result.

A classified study reported by Levy, et al (1963) used a terrain model and TV simulation (Section 6.4.3). The simulated problem was to guide a remotely piloted missile to a target area and acquire a pre-briefed target. For both target area acquisition and more precise target location the observers reported use of roads most often as non-target cues, and patterns of cultivated fields as their next choice.

LaPorte and Calhoun (1966) performed a study specifically for the purpose of investigating target cues. The simulation study was conducted using a forward-looking color motion picture obtained from low altitude over Southern California. The film was stopped periodically during the approach to each target. Many of the stops occurred well before the target was actually visible. At each stop, the subject was required to estimate the location of the assigned target, to record his level of confidence, and to describe briefly, in writing, the most important clues that influenced his judgment. While necessarily subjective and non-analytical the results are illuminating. Based upon 4600 responses, 63 percent of the information about possible target locations was non-target related while 37 percent pertained to the target or the immediate target context. The most frequently reported non-target cues were roads, the next were open areas.

Recent research reported by Mitchell (1971) as described by Parkes (1972a) has also shown that non-target features are more important than target features in determining acquisition performance. This work, a study of subjective estimates of important parameters in target acquisition, indicated that the following three characteristics were of major subjective importance; whether or not the target was visually prominent against its background; whether the target was in a complex or simple environment; and whether there were mapped identification features (i.e., cues) around the target.

Freitag and Jones (1973) report a study of TV target acquisition in which the four target areas were chosen so as to have different cue value: (1) a road intersection which had little extent but a strong cue value, (2) a railroad bridge where two large rivers provided strong cues, (3) a road bridge over a single river with 50 percent contrast, and (4) a second road bridge of same approximate size as (3) but with only 10 percent contrast. While the primary objective of the study was concerned with TV FOV, the effects of strong cue value are clear. Mean search times for various FOV's varied from 3 to 7 seconds and even the low-contrast bridge was acquired in from 3 to 12 seconds. These times are significantly less than those for briefed but uncued targets, reported by Bargert and Fowler (1971) or Snyder and Calhoun (1965).

The U. S. Army has conducted a series of tests to determine the capabilities of helicopter crews to detect and then redetect a selected

target array (as reported by Thornton, et al, 1973). Helicopters with two man crews (pilot and observer) navigated to a target area, and detected a target array of seven tactical vehicles at a range of 4 to 5 Km. The helicopter then went behind mask, maneuvered to a firing position "popped-up", and redetected at 2 to 3 Km. The target array was static on some test runs, and moving for others. The crew members were asked to evaluate what cues they believed to be important in their target detection. The results are shown in Table 5-III.

Natural cues can be highlighted in briefing materials. Useful context cues that have been proven valu[illegible] are any outstanding linear objects (railroad, roads, rivers, river [illegible]nctions) large open areas (airfields, lakes), and items with high natural contrast or large size (buildings, storage tanks, farms).

TABLE 5-III

Detection Cues, TOW/Cobra

Detection Cue	How Helpful	Percentage Ratings by: Cobra Pilots N = 25	Cobra Gunners N = 25
Dust from target	1. None	76	76
	2. Slightly	12	20
	3. Moderately	4	4
	4. Extremely	8	0
Target Size	1. None	32	4
	2. Slightly	16	32
	3. Moderately	48	48
	4. Extremely	4	16
Target Movement	1. None	68	56
	2. Slightly	8	8
	3. Moderately	12	24
	4. Extremely	12	12
Simulated Weapon Signature	1. None	32	24
	2. Slightly	20	12
	3. Moderately	36	16
	4. Extremely	12	48
Target Shadow	1. None	52	48
	2. Slightly	36	32
	3. Moderately	8	20
	4. Extremely	0	0
Color Contrast	1. None	32	4
	2. Slightly	12	48
	3. Moderately	36	36
	4. Extremely	20	12
Metal Glint	1. None	44	44
	2. Slightly	16	52
	3. Moderately	20	4
	4. Extremely	20	0

NOTE: Percentages not adding to 100% are due to "no responses".

Source: Thornton, et al. (1973)

5.4.3 System Search Aids

It is possible, and obviously, may be very desirable, to provide the observer with some sort of aid to help him in his search for targets. Typically, the electro-optical (E-O) devices as a group - TV, FLIR, LLLTV, etc., - are used to aid visual search. Since Chapter 4 discusses E-O devices in some detail they will not be considered here.

Other ways of artificially aiding target acquisition search have been reported, however. Two general types of systems have been subjected to experimental trial. One group makes use of the aircraft's on-board capability to more accurately predict probable target location in space or time. The second general class depends upon some outside (the aircraft) agency to help find the target.

Several on-board techniques have been subjected to experimental evaluation. In general these search aids have not shown a large increase in range-to-target recognition but have shown a significant reduction in numbers of targets missed.

Navigational uncertainty may result in a larger search area. Any way to reduce navigational error should reduce the total search requirement and thus bring about an improvement in performance. One of the more common ways of reducing range uncertainty is by providing time-to-go information, i.e., informing the operator of the expected time of the target's appearance, based upon some sort of navigation procedures.

Rusis and Calhoun (1965) found that the provision of time-to-go information, in the form of a verbal countdown every 5 seconds as the observer flew to the target, significantly improved acquisition probability and number of missed targets as compared with the 'no countdown' situation. There was however, no effect on acquisition range. A motion picture simulation was used in this study. Subjects searched for 20 pre-briefed targets in sequence on the filmed run. The experimenter provided verbal countdown, starting at 65 seconds before the target was due and indicating every 5 seconds, i.e., 65, 60 - - - - 10, 5, 4, 3, 2, 1. Two aircraft speeds were simulated, 198 and 792 knots (367 and 1468 Km/Hr). The interval between targets varied from 1 to 3 minutes at 198 knots (367 Km/Hr) and was one fourth less at the higher speed. The subjects missed 23 percent of targets with no countdown but only 13 percent with countdown. Aircraft speed was significantly related to target acquisition range, although even at the higher speed countdown aided performance. Figure 5-26 shows the results in terms of recognition ranges.

One other possible approach to aid search which uses the aircraft's on-board capability has been experimentally evaluated by Sturm, Snyder, Wyman and Rawlings (1966). Target pre-designation was used to display to the pilot the expected location of the target as computed dynamically from the aircraft inertial navigation system. In a motion picture simulation experiment, 40 subjects were used in a factorial experimental design. The subjects searched for 15 different targets at a speed of 495 knots (917

Km/Hr). "Predesignation" was effected by displaying a bar to the operator on screen (i.e., as if it were seen on the wind screen of a heads-up display). The predesignation bar was in one of three positions, a horizontally oriented cross-range-only bar, a vertically oriented range-only bar, or an intersected range-and-cross-range bar. Three conditions of navigational uncertainty 1/4, 1/2, and 1 nautical mile (.46, .92, and 1.8 KM) CEPs, were also tested. The results showed a significant improvement in target recognition performance from 42 percent with no predesignation to 62 percent for all predesignation conditions combined. Mean recognition range went from 4704 feet to 6876 feet (1434 to 2096 meters). Predesignation in cross-range or azimuth was more effective than that in range only. Smaller size navigational errors also tended to increase recognition ranges.

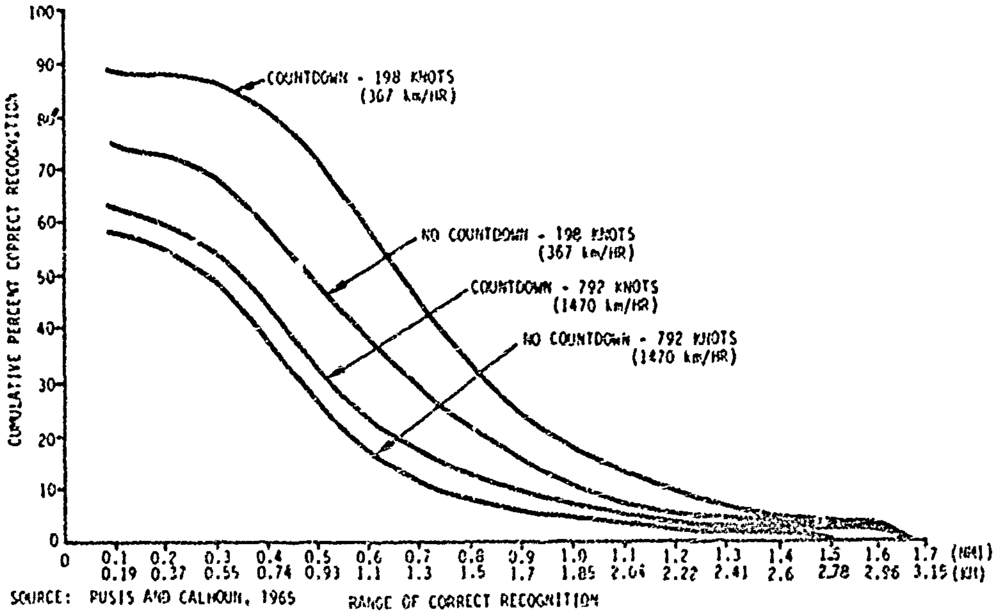


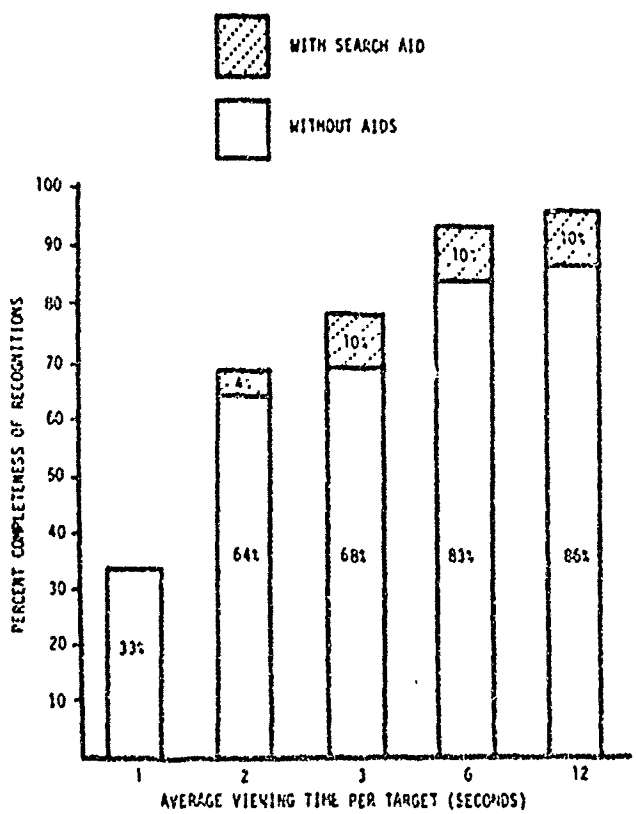
Figure 5-26. Cumulative Percent Correct Recognition as a Function of Ground Range at 198 and 792 Knots for Verbal Countdown and No-Countdown Conditions

Another search aid technique that has been investigated is that of "freezing" the on-board display for several seconds. The results show that this technique can also improve target acquisition in certain applications. Display freeze is discussed in more detail in Section 4.2.11.

Automatic target designation as an aid to visual search was investigated by Marlowe and Dowden (1967) using a terrain table with a TV sensor. The observer task was detection and recognition of tactical type targets in search along a trail, road, or river. A standard 525-line TV was "flown" over a 1:1000 scale terrain table at an altitude of 690 feet (210 meters) and at a varying speed depending upon desired search time per target. The conditions simulated were those of low altitude low speed flight using a fixed look-down sensor angle. The sensor look-angle was 90 degrees with a fixed field of view giving 600 (forward) by 846 (side) feet (183 x 258 m.)

viewing area. Three types of pre-designation were used: (a) the targets were circled with a visible white paper ring placed on the model, (b) were highlighted with small spotlights, and (c) the backgrounds were masked and the target thus stood out. Adequate controls for practice, learning and observer performance were established. The numbers of both targets (30) and non-targets (i.e., 45 similar sized objects not tactical or military in nature) were the same on all runs and all conditions.

Target contrasts, as measured, ranged from 5 to 70 percent. However, 23 of the thirty targets were in the 25 to 65 percent range. Search time was an experimental factor; fly-over speed was varied to give 1, 2, 3, 6, or 12 seconds average viewing time per target. Results indicated no performance difference between the type of aid used, although observers stated a preference for the circle. Use of any aid provided a significant improvement of search efficiency especially at the "fast" 1, 2, or 3 second times. Overall detection and recognition times improved 10 to 15 percent by using the aids. Figure 5-27 shows these results for target recognition.



SOURCE: MARLOWE AND DOWDEN (1967)

Figure 5-27. The Effects on Target Recognition Proficiency of Varying Scene Time and of Display Aids Using Television Simulation

Other techniques that use on-board aids to visual search have been noted in the classified literature, however, no controlled experiments evaluating results is reported. The usual technique uses sensors to detect specific types of radiation. The observer is then cued as to where to conduct search for the target.

Outside (the observer's aircraft) aids to visual search are well known. Here the target or target area is located by some other observer and is marked to make the visual search an easier process. The most typical and best known of these methods is smoke. Target marking by smoke is so well known and so well accepted that no experimental evaluations are reported in the recent target acquisition literature. (During World War II field tests of smoke-types and uses of smoke in target marking were conducted, see Middleton, 1952).

Another often used technique is that of verbal description, a sort of on-the-spot briefing. As noted in the recent target acquisition symposium ("Pilots Panel", in Jones, 1972b) this technique is a very poor way to rapidly acquire targets, even though it is often used.

The development and tactical use of laser designators (to mark targets) and laser spot receivers (to locate them), promises to bring a new dimension to air-to-ground visual search. The target can be acquired by on-ground or low-level observers and illuminated with coherent laser light. The aircraft observer with a laser spot-seeker of some type can now be cued to look at the exact location. Controlled experimental evaluation of laser designation techniques as an aid to target acquisition have not yet been reported in the open literature.

5.4.4 Optical Aids

Aiding visual search by optical devices is as old as the first telescope (and as new as the most recent laser systems). The most used optical aid is hand held; binoculars or a telescope. Using binoculars to search will, because of the narrow FOV, reduce the overall probability of detecting a target. Thus, magnifying optical aids are primarily used for recognition or identification. The target is first acquired by direct visual search and then verified with the magnifying optics. Actual use of binoculars does not appear to be as effective a search aid as supposed, however, the evidence is anecdotal (see "Pilots Panel", in Jones, 1972b, for example). Aircraft motion makes it hard to stabilize hand held optics. When a stabilized optics system is used the result for the observer is often vertigo. The stable, even visual scene he perceives is at variance with the aircraft's perceived vibration and motion. Most observers in aircraft are not able to use stabilized optics for more than a very short time without experiencing some nausea.

Cheever and Horley (1973) conducted a well-controlled field experiment with the objective of determining target identification capabilities by observers using a stabilized optics system in a UH-1 helicopter. Detection was not an experimental variable, the single target per trial was well-cued

with a fluorescent orange panel. The observer's task was recognition (general class of target) and identification (specific model or type). The stabilized optics system provided 1.5, 5, 10 or 20 power magnification; clear, red, amber, and green optical filters were available. The aircraft operated at 95 knots (176 Km/Hr) airspeed and at 2000 feet (610 meters) altitude. The flight course started at 8 Km from the target and closed from there. The observers used the 20X magnification over 3/4 of the time and the 10X for all but one of the remaining trials. The results indicated that even with this stabilized optic system neither troops nor vehicles could be accurately identified (i.e., a probability greater than .90) at ranges exceeding one kilometer. Figure 5-28 shows the cumulative probability of identification using stabilized optics.

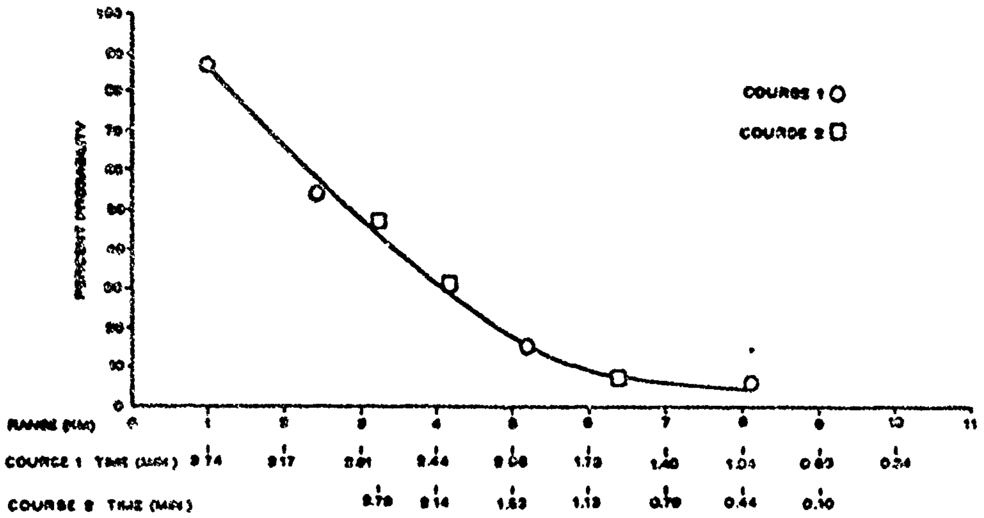


Figure 5-28. Approximate Cumulative Probability of a Correct-By-Nation Vehicle Identification versus Slant Range and Time

Another "optical aid" some times used is sunglasses. In theory the glasses should reduce some glare and help to see through haze. Actually, this does not seem to be the case.

Heckart, et al (1971) investigated the effects of wearing yellow sunglasses (Bausch and Lomb Kalichrome C) to improve the observers' optical environment. They found no difference in target acquisition performance in a field test between wearing sun glasses and not. The subjects observed from the nose position of a B-50 flying at 180 knots (334 Km/Hr) speed and at 3,500 feet (1067 meters) altitude. Mean percent of target sites detected was 69 percent for those with glasses and the same for those without.

5.5 Summary

5.5.1 Design

This review of the literature on air-to-ground target search has many ramifications for the designer of target acquisition systems and/or aids.

In the case of aircraft designed for or being used for direct visual target acquisition, most of the design recommendations have to do with providing sufficient forward visibility for detecting and recognizing ground targets out through the windscreen without impediments such as engine nacelles, fuselage sections, wings, antennae, etc. Another obvious recommendation is to prevent, if possible, glint or reflections off the windscreen into the eye of the observer at various sun angle combinations. The observer should be so placed in the cockpit that he has maximum ground area available for searching with minimum masking. If the aircraft is to be flown at high speed and at low altitude, he should have maximum target availability from directly ahead to almost directly below the aircraft to facilitate eyeball tracking (following) of the target in order to remove or minimize the high rates of angular movement of these types of mission conditions.

In aircraft having particularly high vibration such as in helicopters means should be found to reduce the degrading effect of this vibration on target acquisition. One method of doing this is by designing seats with built-in shock or vibration-decreasing mounts. These mounts should either reduce the vibration to noneffective amplitudes or transduce the vibratory spectrum so that eyeball sympathetic or forced vibration is eliminated or reduced. Vibration factors are particularly important when visual aids such as binoculars are used in searching for ground targets. Stabilized optics are one method of combating the vibration and aircraft movement effects which tend to make search and visual tracking difficult if not impossible under turbulent or aircraft maneuvering conditions.

In the design of electro-optical systems to be used in search for ground targets, the design parameters are considerably more numerous. Scene stabilization and gimbal order have been shown to have considerable impact on the effectiveness of the cockpit observer. The gimbal system should provide scene stabilization for both searching for and for tracking of possible targets. The field of views of the sensor must be selected so as to provide a compromise between maximum ground being covered and the magnification of the scene for sufficient detail so that the observer can determine whether a possible target exists in the terrain being imaged. The display located in the cockpit should have sufficient quality, resolution, brightness, MTF, size, and viewing distance so as to maximize scene search by the observer. (This topic is covered in more detail in Chapter 4, Displays).

5.5.2 Operations

The literature has also emphasized the importance of training and briefing in air-to-ground target acquisition performance efficiency. Airborne observers should be taught scanning and search skills necessary for maximum ground coverage utilizing peripheral vision for rapid scanning and the ability to quickly reject nontarget clutter. Although this is being being done at the present time, the equipment is available for use in training that has been used in research on search behavior.

Several studies have indicated that adequate briefing is very important in detecting targets where scene search is required. Every effort should be made to improve the briefing methods presently being used by the operational forces such as photographs, maps, etc. Allied to adequate briefing is the use of "cueing" devices such as radar, navigational equipment, etc. The use of these equipments considerably improves the efficiency of search behavior by reducing the area to be searched. Mission planning should carefully consider the type of terrain to be searched, the type of targets to be located and intelligence information when assigning type of aircraft, number of aircraft, altitude and speed to be flown. Multiple aircraft should be used to search for difficult targets to increase detection probability, particularly if the targets are high value; a single aircraft should use multiple observers to achieve the same effect. Search patterns should also be devised to take into consideration the difficulty of detection, using tighter patterns over less territory when target/terrain conditions make for difficult detection, widening the patterns when searching for "targets of opportunity", etc.

Another important factor is the selection of flight personnel who have the basic visual (physiological) equipment such as visual acuity, movement threshold, and perceptual skills to make good airborne observers. Although a good part of search skill efficiency is learned, the basic capability should exist prior to training. Standardized tests could be devised to both select and train observers to scan rapidly and process visual information rapidly.

CHAPTER SIX

PREDICTION AND EVALUATION OF TARGET ACQUISITION

6.1 Introduction

This chapter discusses the evaluation and prediction of operational target acquisition, the techniques that have been used, the effectiveness of those techniques, and, as a result, how operational target acquisition performance can be predicted and evaluated.

Mathematical models, simulators, and field tests will be discussed in that order. While this order of presentation is somewhat arbitrary, it does reflect the classical scientific approach: Develop hypotheses (models) based upon experimental and other evidence; test the models in controlled conditions (simulators) and verify the performance in real world conditions (field tests); and finally, use the results of these tests to further modify and update the models.

The review of prediction and evaluation techniques will show that the reported results are inconsistent among various methods. The reasons for this are as complex as the problems of target acquisition. At this time it is impractical to measure or predict, and/or control, all variables involved in target acquisition. Thus, the practical evaluation process relies on a series of controls and simplifying assumptions. In many of the evaluation and prediction techniques, these controls or assumptions are often not specified in detail. The types of simplifying conditions and assumptions used also depend upon the evaluation or prediction method. Mathematical models, for example, most often ignore cognitive and motivational factors. While field tests with observers will obviously include these same factors in some degree, the presumption is often made that all observers are the same. Rarely are these assumptions or simplifying conditions spelled out. They usually must be inferred from the conditions of the test or contents of the model. But each evaluation and prediction technique that has been used has certain advantages and limitations, due in large part to the inherent assumptions of the methodology involved.

6.1.1 Evaluation Methods

The three techniques that have been used to assess and predict target acquisition procedures and systems are:

1. Mathematical Models

2. Simulators

3. Field Tests

The major reason for using these techniques is to be able to predict operational performance. Mathematical models are usually considered primarily as prediction methods, while field tests and simulator evaluations are considered as test methods. Yet all three are useful for both evaluation and prediction. By varying the mathematical model parameters, the concepts can be "tested." Field and simulator tests are most often used to evaluate target acquisition systems or techniques. The results of these tests, however, can be used to predict the effectiveness of that technique or system in other operations. The results of the tests also can be used as inputs to models or as partial validation of the models.

Figure 1-2 is repeated here as 6-1 for emphasis and further reference. The figure shows those elements that the review of the research has shown to be important.

6.2 Mathematical Models

In this section the emphasis is upon mathematical models of the total target acquisition process. Certain important submodel developments, such as atmospheric effects, are noted in earlier chapters. System models consider the problem from target to observer as a combination of events from target conditions through the atmosphere to the observer, or to a sensor/display system, and then to the observer.

6.2.1 Model Approaches

Modeling of a complex problem such as air-to-ground target acquisition may take one of two different approaches.

The first depends upon basic research, and is interested in finding the precise relationships between the key variables. The research is quantitative and tries to understand how, why, and how much each variable affects performance. This basic approach is usually long-term and is often stimulus, rather than response, oriented. The basic research approach is analytic-constructive (Bliss, 1966). The problem is broken down into key elements, the separate effects of these elements are analyzed, and the individual parts are combined in some logical fashion into a predictive model. The traditional approach to target acquisition models has been, first, to model the search and detection process. The model builder then includes the necessary size requirements, usually or as a minimum visual angle subtended at the eyeball or as a resolution term for electro-optical (E-O) systems. Characteristics of the target

TARGET BACKGROUND PARAMETERS	AIRCRAFT PARAMETERS	ENVIRONMENT PARAMETERS	SENSOR DISPLAY PARAMETERS	OBSERVER PARAMETERS
Type	Altitude	Visibility	Sensor Type	Fixation
Size	Range	Cloud Cover	Field of View	Search Time
Shape	Speed	(Sky-Ground Ratio)	Resolution	Search Pattern
Contrast	Offset	Sun Angle	Contrast Ratio	Visual Acuity
Color	Target Exposure Time	Illumination Level	Gamma	
Luminance-Reflectance	Type Aircraft	Diurnal Variation	Signal-to-Noise	Experience
Texture	Crew Size	Seasonal Variation	Frame Rate	Training
Motion	Seat Position	Scintillation	Interlace	Expectation
Shadow	Apparent Motion	Glare	Integration Time	Motivation
Terrain Type		Attenuation	Pointing Angle	
Vegetation		Transmittance		Task Load
Masking		Apparent Contrast	Display Size	Stress
Camouflage		MTF	Aspect Ratio	
Clutter			Viewing Distance	Number of Observers
Cues			Displayed Signal-to-Noise	Prebriefing
				Cueing
Distinctiveness			Color	Search Aids
Conspicuity			Spot Wobble	
Embeddedness			Scene Rotation	
Ambiguity			Display Freeze	
Confusability			Enhancement	

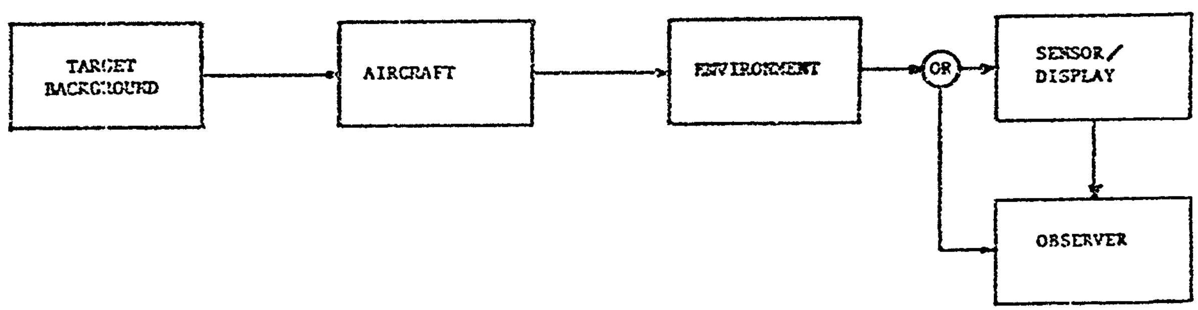


Figure 6-1. Typical Parameters in Air-to-Ground Target Acquisition Process

shape and of the related background are considered, either as confusing objects, background clutter, or as a signal-to-noise ratio for models of E-O systems. The effects of geometry, relative speed, altitude, and atmosphere are used as given values from other models, handled as inputs, or ignored. Human performance problems are most often not considered. The model builders naturally tend to concentrate on quantitative variables for which numerical values are well established.

The second approach is operationally oriented. The modeler predicts performance in a specific real-world situation often based upon field test data. The values of variables are limited to the actual values measured in an operational environment. The response as well as the stimulus is an important consideration. The operational model is usually less precise and may not be as mathematically elegant. For many target acquisition problems, however, the operationally-based model may prove to have more general predictive power.

Most of the best known target acquisition models use the analytic-constructive approach. These models are based upon what is known about human vision, the effects of the atmosphere, the transmission of light (or other electromagnetic energy), and the geometry of aircraft-to-target search area. The models are, as a result, often difficult to use in the operational situations, tend to emphasize only target detection, require extensive mathematical processing (meaning computers), and most often are not well validated. (See, for example, Greening, 1973.) However, previously the analytic-constructive approach was almost the only practical one. Sufficient field test data and a better understanding of the human factors elements in the target acquisition process are more recent developments. As a result, many of the later modeling efforts include both basic and applied information.

6.2.2 Model Classes

The generalized air-to-ground target acquisition models are sometimes also divided into two classes depending upon the type of "sensor" involved.

a. Direct vision models. In these models the observer is airborne and is presumed to be searching only with his eyeball.

b. Electro-optical models. In these models the observer is presumed to be searching a cathode ray tube (CRT) display while a sensor scans the target area.

In practice this class distinction is not a clearly defined difference. Several of the better known direct vision models have terms that can be added to allow consideration of E-O sensors and indeed, the MARSAM II

and GRC models were originally designed for E-O sensors (Schaefer, 1968 and Stathacopoulous, 1967). In turn, the E-O models often include terms and concepts from direct vision model formulations. An excellent detailed analysis of direct vision models is reported by Greening (1973). A summary and analysis of the principal E-O models have been reported by Mendez and Freitag (1972)[1].

6.2.3 Early Model Development Influences

The history of target acquisition modeling parallels that of target acquisition research. During and before World War II the problems of finding targets from the air became obvious; along with the operational need came a requirement to predict target acquisition capabilities. The problems of acquiring "targets" at long ranges had been subject to research well prior to 1940, as well as to analysis and even modeling of the atmosphere (see Middleton, 1964). A concerted effort, however, was made during the war on the problems of assessing and predicting target acquisition.

A systematic attempt to model the air-to-surface visual search process was conducted by the U.S. Navy during World War II. An Operations Effectiveness Group (OEG) team developed an air-to-sea search model which forms the basis of many of the present models (Koopman, 1946). The OEG modeling effort was a very broad one, including surface and airborne observers, radar and sonar sensors, in addition to air-to-surface visual performance. The model of visual search was prepared by E.S. Lamar. Lamar's work on visual detection models is available in the NRC publications, "Visual Search" (Morris and Horne, 1969).

6.2.3.1 "Visual Lobe" Concept

Lamar's approach to the air/sea and detection problem was to use relevant psychophysical laboratory data. From these data on human performance, Lamar developed the concept of a "detection lobe," similar to a radar concept which had just come into use. "Visual lobe" is a mathematical construction which simplifies calculation. For some probability,

[1] The discussion of the material regarding target acquisition modeling is essentially from Greening (1973). Particular credit is given to the excellent target acquisition model evaluation by Dr. Charles P. Greening. The materials are used with the permission of the author and the Naval Weapons Center, China Lake, California. Rather than duplicate an outstanding effort, the authors have chosen to use Greening's material directly. In the interests of reading clarity and ease, detailed indications of quotations have been eliminated. Any errors of editing or interpretation must, of course, be the responsibility of the authors.

usually .50, there will be a certain probability of an off-visual axis angle which bounds the shell of the "visual lobe." Inside the lobe, the target is assumed to be detected and not outside it. Lamar's visual detection lobe equations defined the value of target/background contrast which would be barely discernible, as a function of target size and of visual angle off-axis. His defining equations converted to an operationally useful form are:

$$C_T = 1.55 + \frac{15.2}{\beta^2} \qquad \text{for } \theta \leq 0.8°$$

and

$$C_T = 1.75\,\theta^{1/2} + \frac{190}{\beta^2} \qquad \text{for } \theta > 0.8°$$

where β is angular subtense of the target (min)

θ is angle off the visual axis (deg)

C_T is apparent contrast in percent.

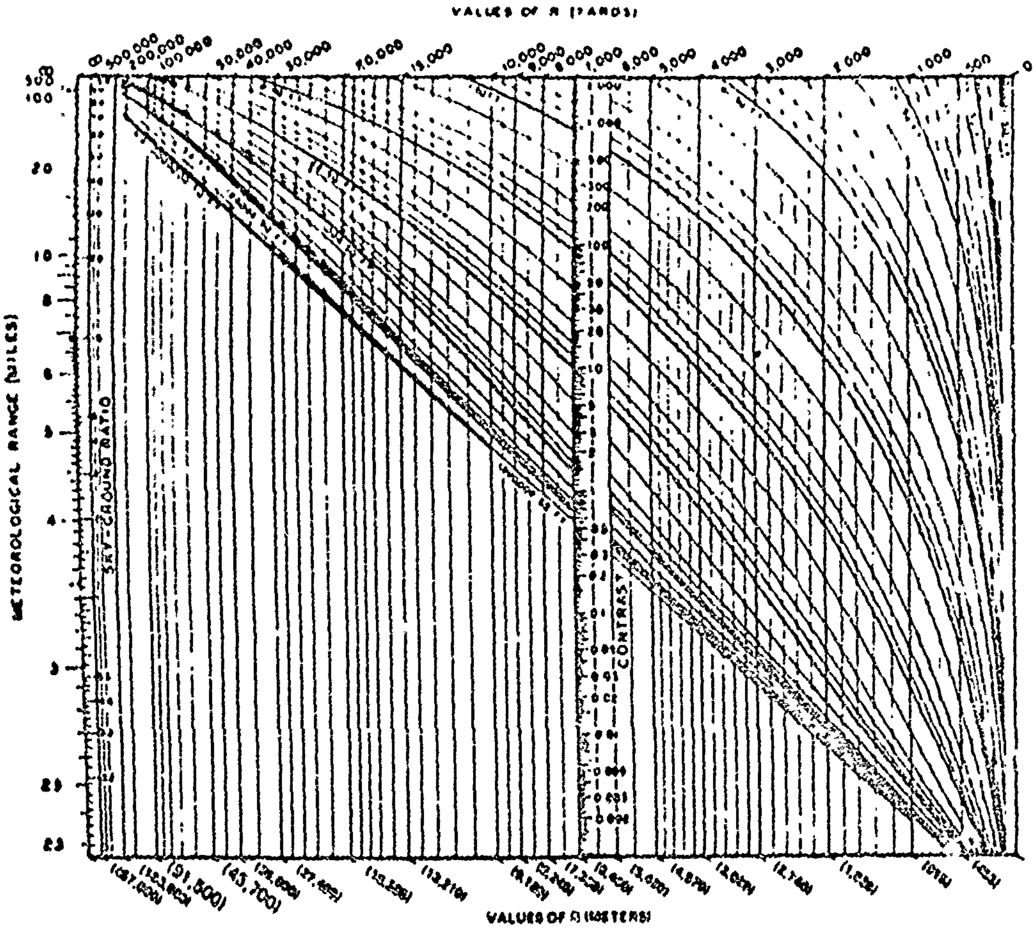
Lamar then developed probability of target detection for linear and area search, as a function of target angle subtense at the eye, contrast, and search area. The expressions were based on assumptions of random search, which is appropriate for air-to-sea situations where the visual field is essentially unstructured.

6.2.3.2 Atmospheric Effects

Also during World War II the camouflage section of the National Defense Research committee did an extensive study of the visibility of distant objects through the atmosphere (Duntley, 1948). During the same period, Blackwell (1946) was conducting the detailed studies of the contrast thresholds of the human eye. (See paragraph 2.3.4, Chapter 2). Based upon these Blackwell data and related works, a mathematical description of the theoretical threshold of visibility was developed. The results were presented as a series of nomographs which predicted the liminal visibility of a circular shaped target seen through the atmosphere against a background of horizon sky (Duntley, 1948), a situation not usually typical of the conditions involved in air-to-ground target search.

A nomograph for slant range looking down through the atmosphere, more typical of air-to-ground search, was also developed. A version of this is reproduced here as Figure 6-2 (from Middleton, 1952, page 129). The nomograph requires knowledge of target size, meteorological range, sky-ground ratio, and target-to-background contrast. Depending on the size of the target, the threshold slant range in yards can be determined. To use the nomograph in Figure 6-2, place a straight edge to connect the proper sky-ground ratio with the inherent scene contrast. Hold a pencil at the point where the straight edge intersects the right hand edge of the nomogram. Rotate the straight edge to the correct point on the meteorological range scale. Then locate where the desired target size

line intersects the straight edge. Read down (or up) to the slant range value. Note that the slant range obtained is the expected maximum detection range for a round target under ideal conditions with a theoretical 95 percent probability of success. This or the Duntley slant range liminal visibility submodel is still used in many target acquisition modeling efforts.



SOURCE: MIDDLETON, 1952

Figure 6-2. Sighting Range of Circular Objects on the Ground, Seen From the Air in Full Daylight, Based on the Tiffany Data for Circular Targets, at a Probability of Detection of 95 Percent

6.2.3.3 Target Size and Contrast

The early research by Blackwell regarding similar target size and contrast is used as basic data in most detection models. A second source of data also used for target detection models is the series of studies performed by Taylor and others at the University of California Visibility Laboratory. Simple disc targets were used varying in size from 1 to 120

minutes of arc and in contrast and luminance. The conditions were modified to include cases in which the target was off the central visual fixation axis by known amounts (see Figure 2-14). Detection thresholds for objects other than circles have been investigated experimentally by several workers, including Lamar, and by Blackwell and associates. The use of the "circle" data has seemed relevant. Generally speaking, detection is not affected by the change from circle to rectangle, at least until the length/breadth ratio reaches ten (Davies, 1971).

The work done by Koopman, Lamar, Blackwell, and Taylor primarily concerned search and detection in a uniform visual field. While visual capability such as shown in Figure 6-2 bounds visual search, it is not realistic to predict target acquisition system performance entirely this way. Thus, as modeling of target acquisition developed, the models have also considered target shape, masking, clutter, and cueing, and a number of other variables.

6.2.3.4 Resolution for Recognition

Simple detection of an object in the visual field - the model developed by Lamar - is not the complete target acquisition process. Recognition of what the object is and, under certain circumstances, identification of the exact object are required. The criteria for recognition and identification adapted and used by most analytical models have been those developed by Johnson (1958) (see Chapter 4, Table 4-I and Section 4.2.1). The "Johnson criteria" require four resolution elements or line pairs for recognition. The report by Brainard (1965), which established 3.2 line pairs for recognition, has also been used in several models.

6.2.3.5 Clutter

In tactical operations the target usually is one object among many in the visual field. Target acquisition requires searching to select the target out from the non-targets. The reference data most used in the models are those of Boynton and Bush (1955,1956,1957). (See Chapter 3, Section 3.2.8). Those studies investigated in laboratory search experiments the relationship between number of objects, size, contrast, spacing, and shape. They developed a mathematical description of their data as follows:

$$\text{Log}\ (C_T - 2.34) = 0.0857D + 1.565\ \text{Log}\ \left(\frac{N}{t} + 3.021\right) - 1.52$$

where

C_T is percent contrast of target to background

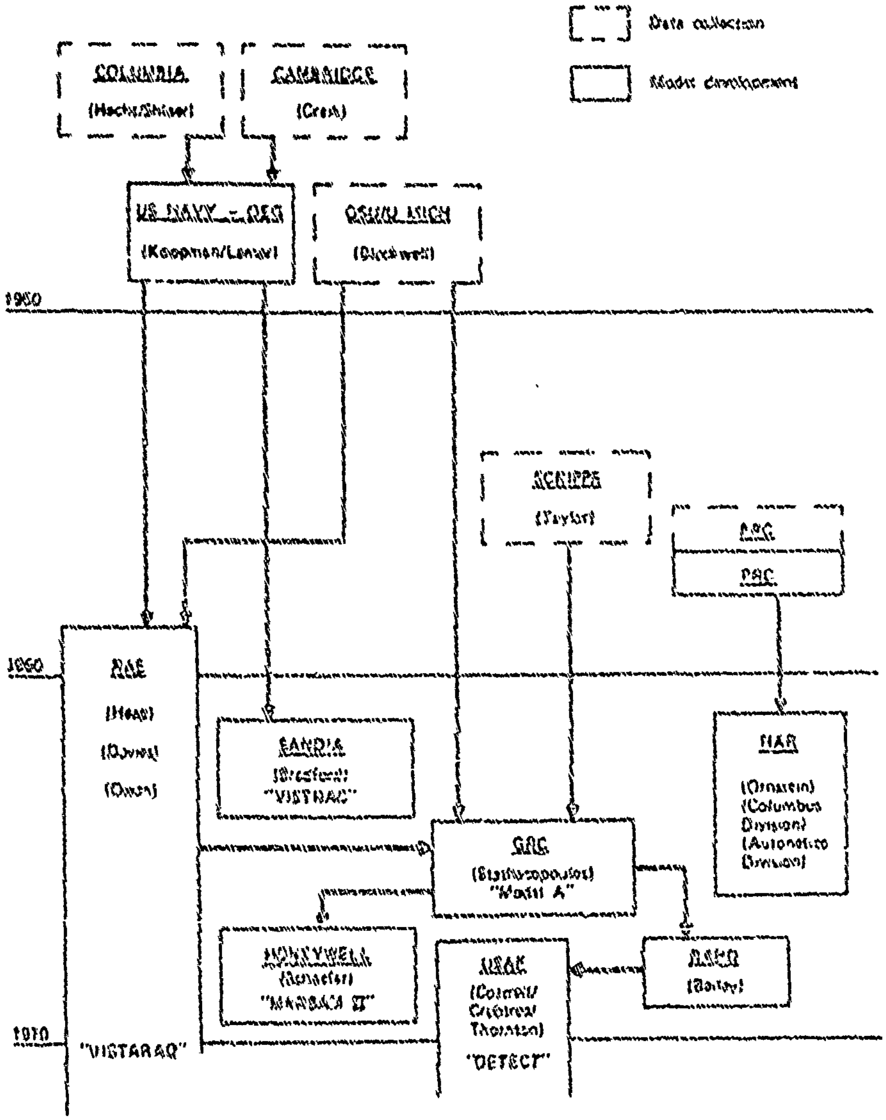
D is distance in meters to the searched area

N is the number of "confusing objects" in the background

t is the search time in seconds.

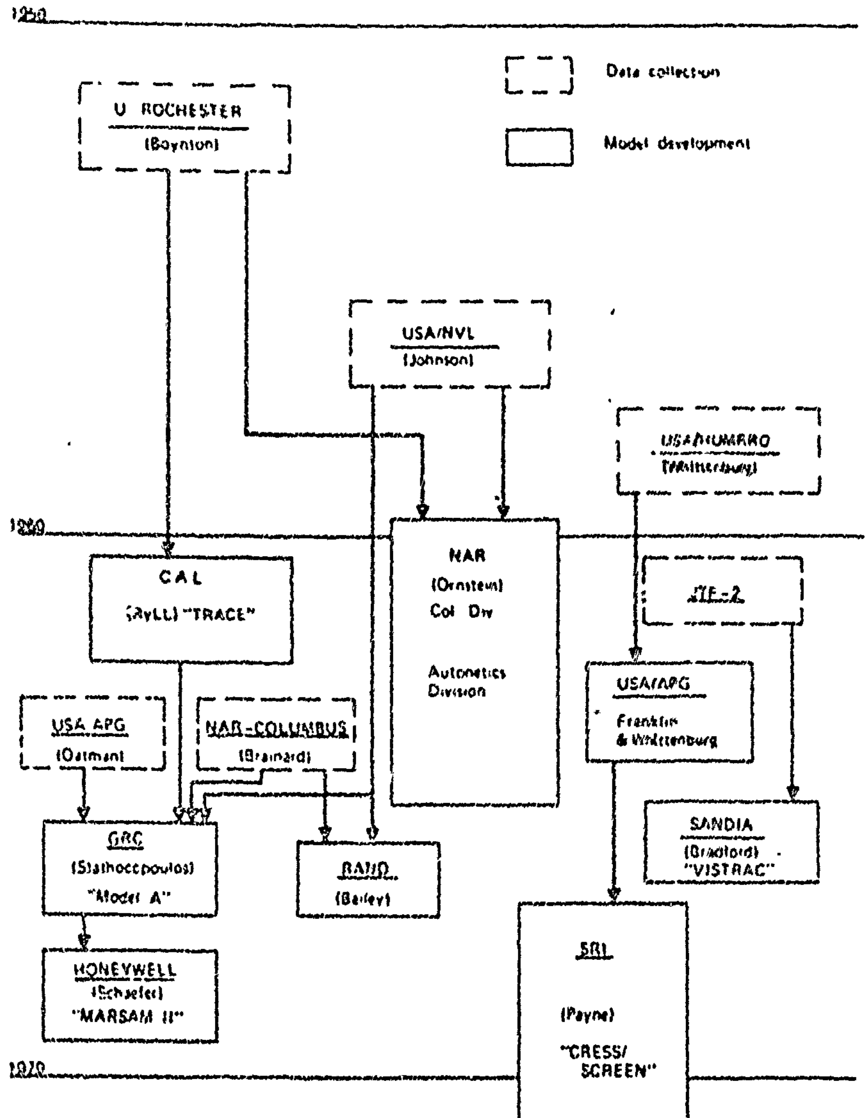
6.3 Target Acquisition Models

The major events in visual target acquisition model development are shown in Figures 6-3 and 6-4. A detailed review of the most used models to include data processing requirements can be found in Greening (1973). As is evident from the figures, some models are only concerned with target detection while others include the recognition and acquisition functions. All but three of the visual models are analytic-constructive and based primarily upon laboratory "search" data. Most of them have not been fully validated in an actual field test.



SOURCE: GREENING, 1973

Figure 6-3. Major Events in Target Detection Model Development



SOURCE: GREENING, 1973

Figure 6-4. Major Events in Target Recognition and Acquisition Model Development

Certain model approaches have been influential because of their unique approach, new concepts, incorporation of original ideas, or even widespread use. These models include the early efforts of Koopman/Lamar, the GRC and Bailey-Rand concepts, MARSAM II, and the Franklin and Whittenburg model. The more significant and important models are reviewed in this section.

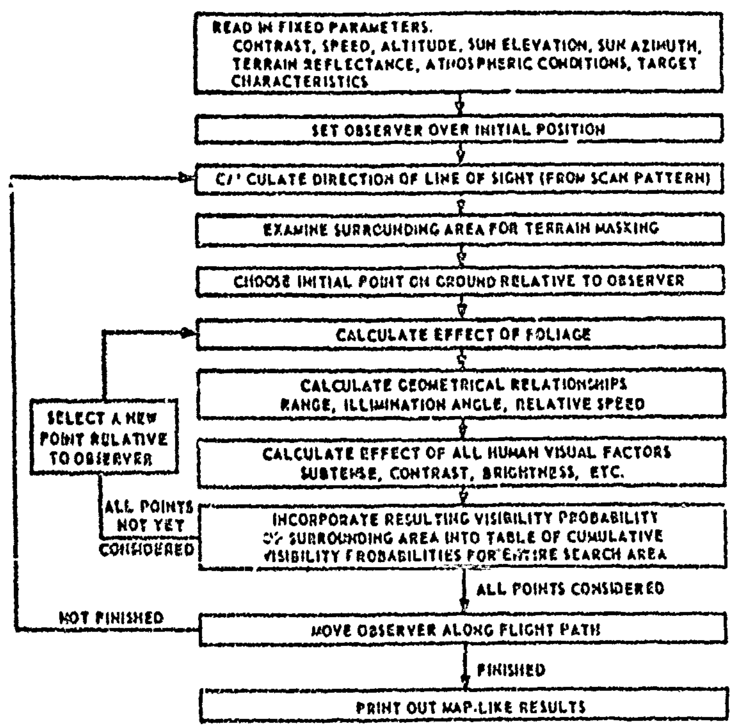
Many target acquisition models are in use, primarily in private organizations and thus not normally available, particularly when E-O

sensors are used. Models that are discussed in this section, however, represent the most significant in terms of formulation, approach, or wide use. To the best of our knowledge, no other models are available which are more appropriate or particularly unique. Greening (1973) in his review of visual acquisition models lists 20 different models. A review of all models practical for consideration in this section included those 20 as well as 17 more. Of the 37 models, 10 are included in this section because they are unique, well validated, or widely used.

6.3.1 The CAL Ryll Model

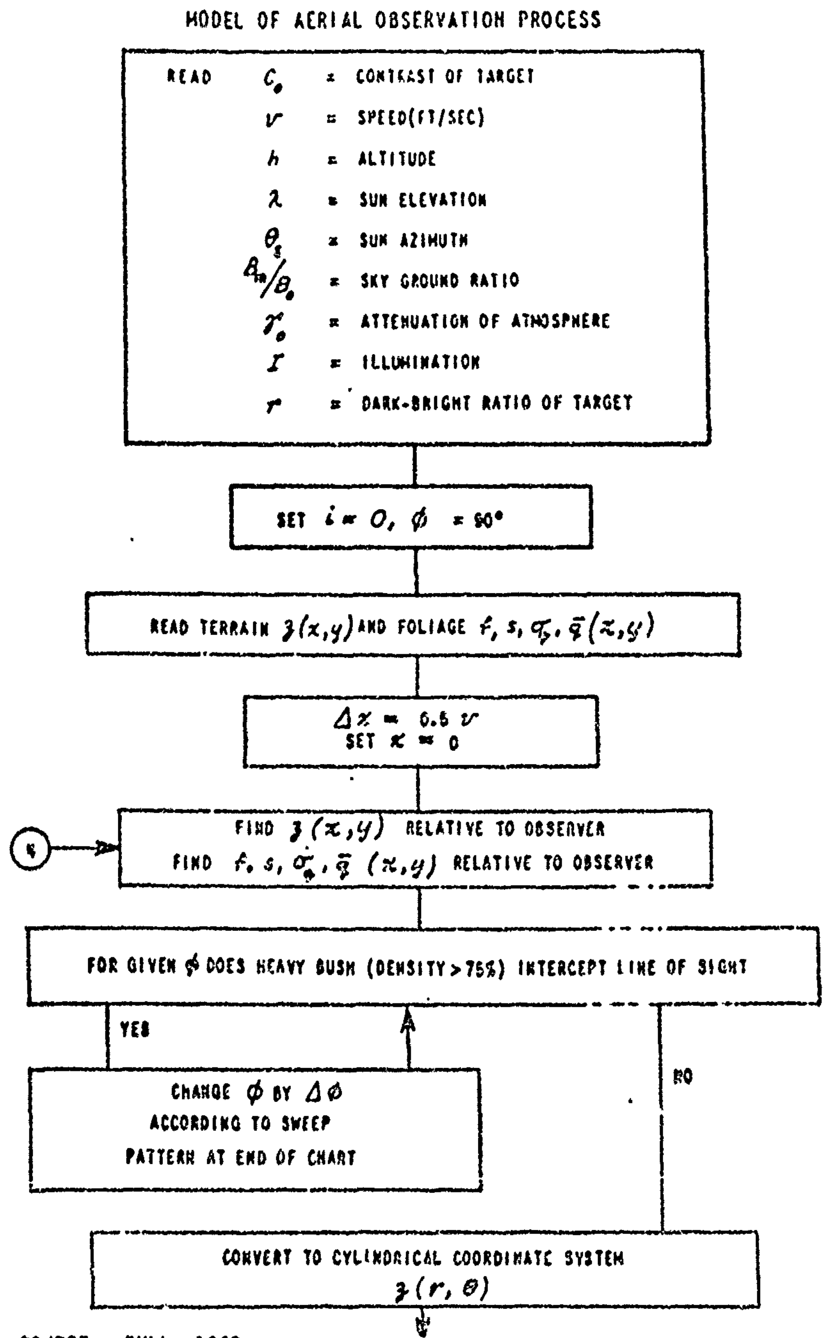
This model was developed by Ryll at Cornell Aeronautical Laboratory (CAL) under contract to the U.S. Army (Ryll, 1962). The objective was to predict observer performance from low speed, low flying Army aircraft.

Ryll with direction from the project director, Arthur Stein, used a straight-forward analytic-constructive approach. A detailed series of flow charts was developed. These charts are excellent examples of the carefully developed analytic-constructive approach. Figure 6-5 is a copy of Ryll's basic flow chart of the target detection probability process. Figure 6-6 is the detailed flow chart used for the aerial observer model. As is evident in Figure 6-6, much emphasis was put on the problems of terrain and vegetation masking, largely because of the contract monitor's interest (A. Stein, personal communication, June 1974).



SOURCE: RYLL, 1962

Figure 6-5. Basic Flow Chart for Ryll Aerial Observer Model



SOURCE: RYLL, 1962

Figure 6-6. Detail Flow Chart of Ryll Model of Aerial Observation Process

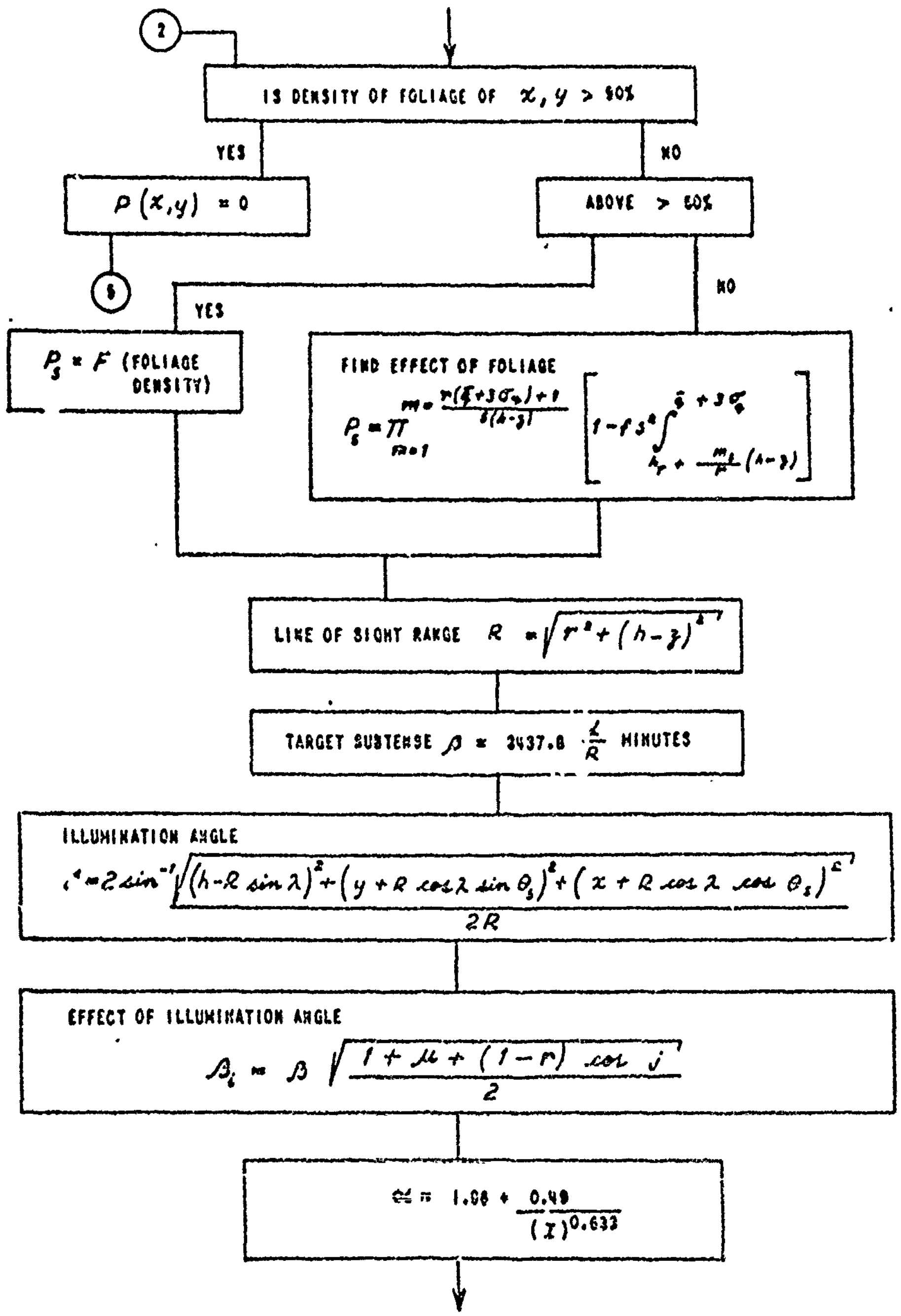


Figure 6-6. (Continued)

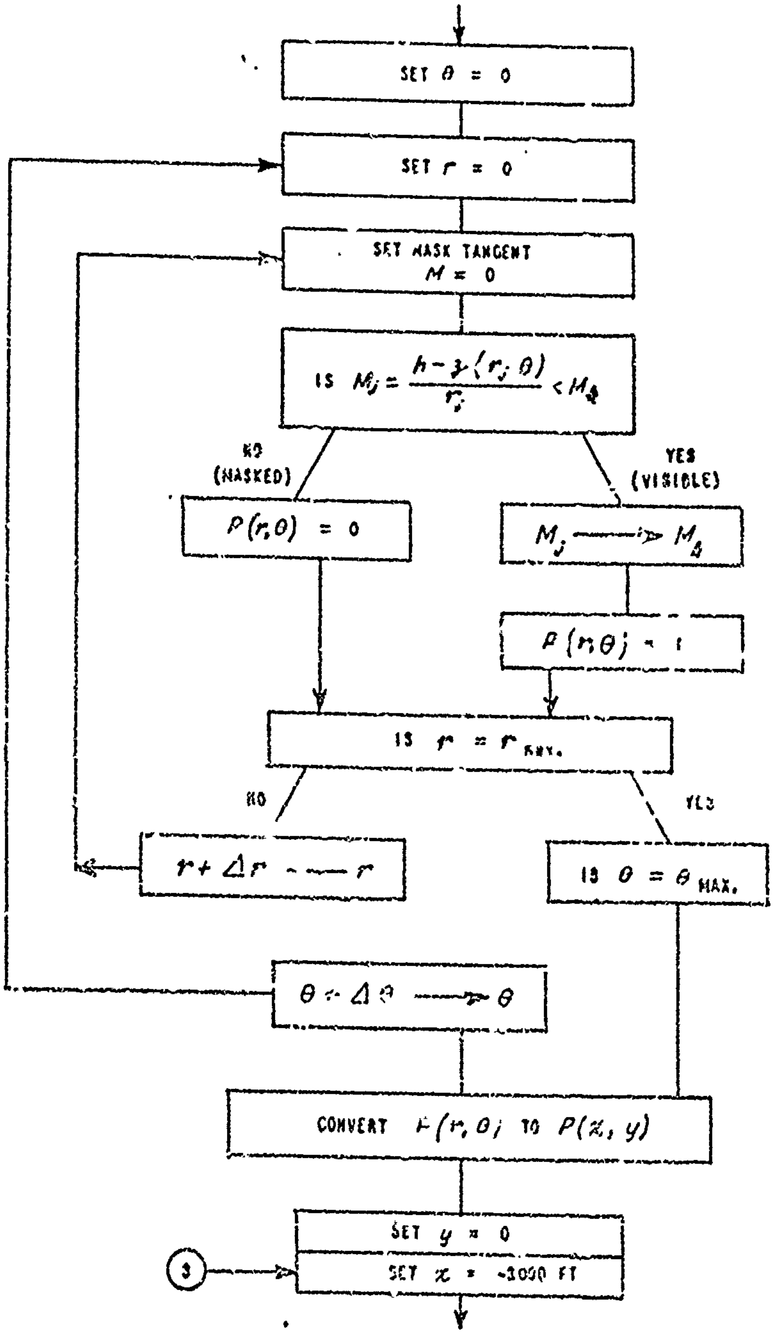


Figure 5-6. (Continued)

$b = f(I)$ INTERPOLATION FROM TABLES

ANGULAR VELOCITY OF TARGET

$$\omega = 57.3 \sin^{-1} \frac{\sqrt{(h-z)^2 + (y)^2 v}}{R}$$

EFFECT OF VELOCITY

$$\beta_0 = a + b\omega^3$$

$$G = \frac{(h-z)\cos\phi + (z\cos\theta + y\sin\theta)\sin\phi}{R}$$

$$\alpha = 114.6 \tan^{-1} \sqrt{\frac{1-G}{1+G}}$$ (IN MINUTES)

SEE APPENDIX I

EFFECT OF OFF-ANGLE

$$\beta_\alpha = (1 + 0.643\,\alpha)\,\beta_0$$

IS $\left|\frac{h-z}{R}\right| < \frac{1}{100}$

$R \longrightarrow \bar{R}$

ATMOSPHERIC RANGE

$$R = 21{,}700\,R \left[\frac{e^{-h/21,700} - e^{-z/21,700}}{h-z}\right]$$

Figure 6-6. (Continued)

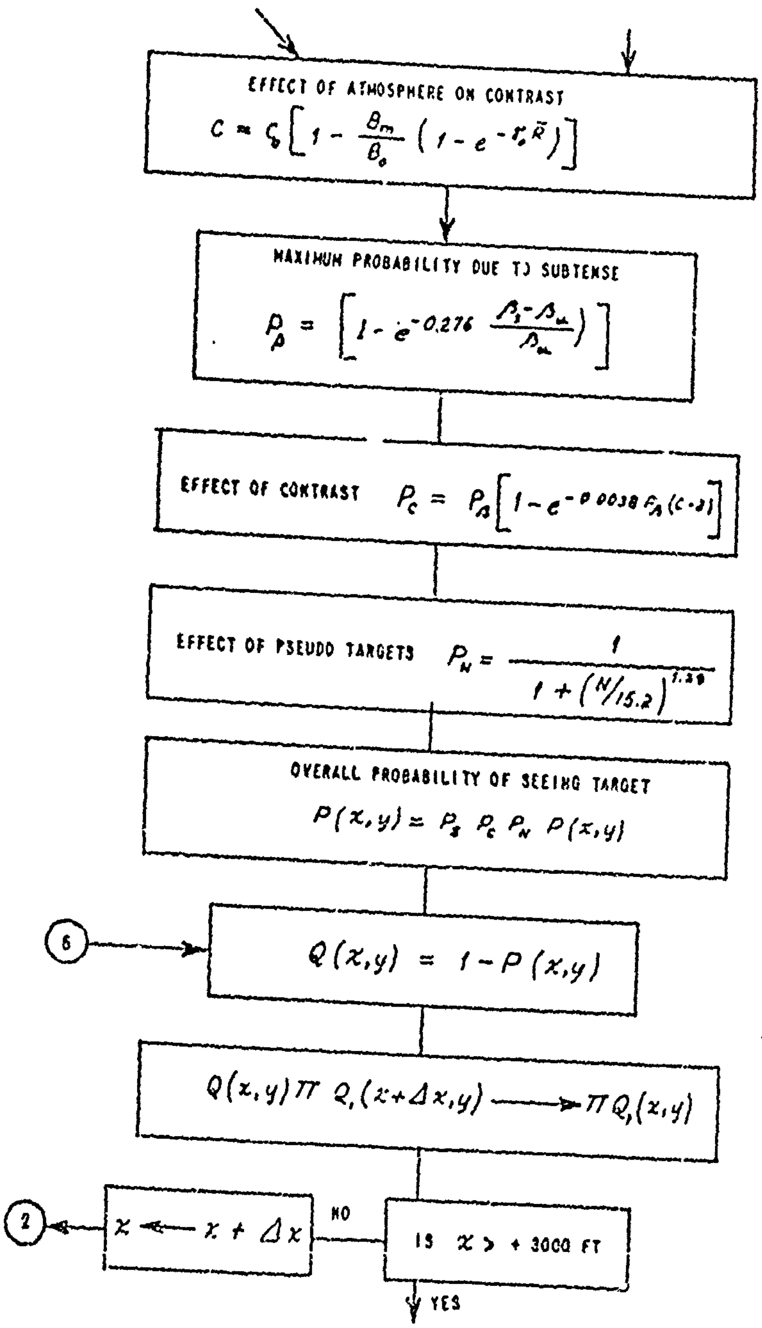


Figure 6-6. (Continued)

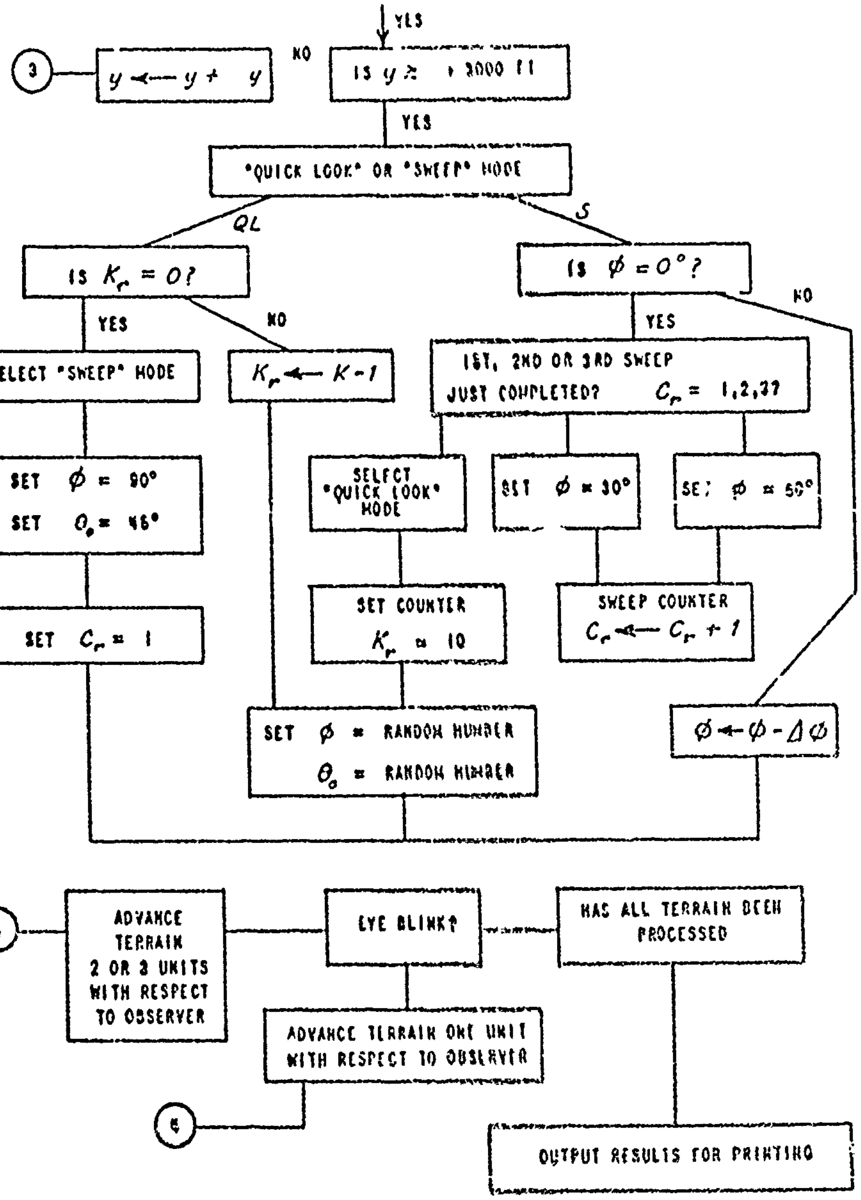


Figure 6-6. (Continued)

In this model, the output was an "overall probability of seeing the target" for any target position for each glimpse. This probability is derived from the product of P_B (probability target is unmasked), P_c (probability of detecting contrast), and P_n (effect of trees and non-target objects). The output is a plot of the search area with a probability value for each point in the area. The "Comprehensive Model" was never computer programmed, however (A. Stein, Personal Communication, June 1974). Instead, a "Simplified Derived Model" was completed. This model provided single-glimpse detectability of a specific target (5 foot sphere, 100 percent contrast) in a specific terrain (flat, no foliage) with bright illumination, no shadows, and no atmosphere. A number of plots of detectability as a function of altitude, speed, and look-down angle are presented. Figure 6-7 is a copy of the typical output.

The value of the Ryll model is in the systematic consideration of variables as shown in Figure 6-6. These concepts have reappeared in subsequent models such as the GRC Model A and MARSAM II, and the "Confusing Objects" Submodel of Greening (1973). There are no reported field tests of the Ryll model.

6.3.2 GRC Model A

The General Research Corporation Model A was designed for a classified E-O system and includes an operator/display element for a fixed frame E-O system (Stathacopoulos, 1967). The GRC model has proved to be an influential source of ideas for target acquisition modeling. The GRC formulation included ideas originally developed by Bailey, although the Bailey-Rand model (Section 6.3.10) was formally published at a later date (Greening, 1973).

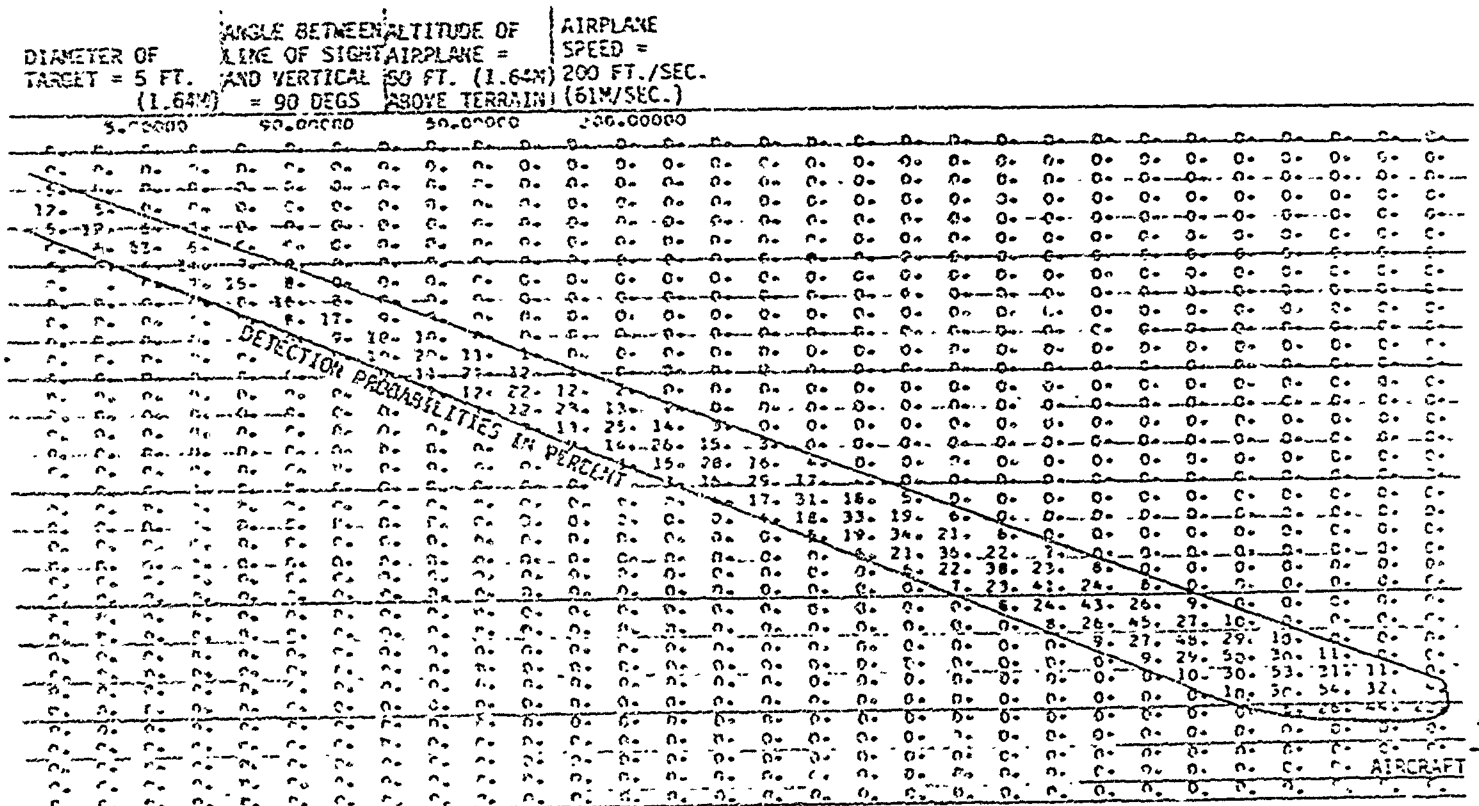
The model partitions the target acquisition process into a number of functional blocks (e.g., search, recognition, confusing objects scrutiny) which are treated as though statistically independent. For each block, relevant experimental data are used and modeled analytically. Subsequent to its publication, the GRC Model A approach was used, with only minor changes, for major portions of the MARSAM II Display and Observer submodels and has also provided a part of other model formulations.

The model structure is shown in Figure 6-8. The probability of detecting and recognizing a target is:

$$P_{DR} = P_1 P_2 P_3 P_4$$

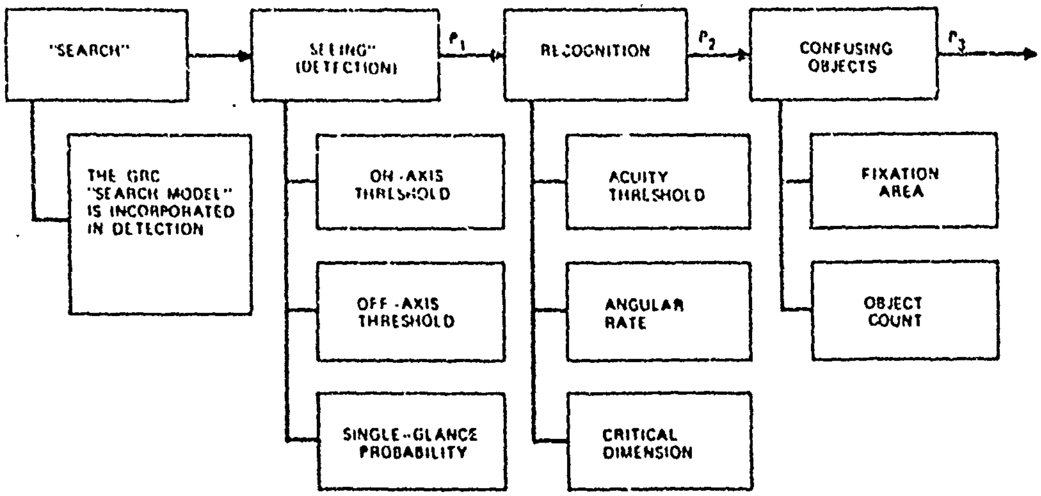
where

- P_1 is probability of "seeing" target (a search submodel), based on Blackwell's laboratory data
- P_2 is probability of recognition
- P_3 is a multiple-object confusion probability
- P_4 is a signal-to-noise, degradation factor (not needed in the direct visual case).



SOURCE: RYLL, 1962

Figure 6-7. Ryll Model Output, Probability of Detecting a 5-Foot Diameter Target in 100 Percent Contrast



SOURCE: GREENING, 1973

Figure 6-8. GRC Model A - Observer Model Structure

Search and "Seeing" Submodel

P_1 is based on the assumption of a fixed amount of time (the frame time) to search a fixed field (the displayed sensor FOV) under a limited range of luminance levels, representative of CRT displays. It is assumed that the target is randomly placed in the field and that the observer's visual lobe is randomly moved across the field from glimpse to glimpse. Under the assumptions,

$$P_1 = 1 - (1 - P_g)^n$$

where

P_g is the single glimpse probability of detection

n is the number of glimpses in one frame time.

The single glimpse probability is determined from:

$$P_g = \iint_{xy} P_D$$

where P_D is evaluated across the display area from three equations:

$$P_D = \begin{cases} 1/2 \pm 1/2 \left\{ 1 - \exp \left[-\frac{2}{\pi} \left(\frac{C_R - 1}{0.39} \right)^2 \right] \right\}^{1/2} & \text{for } C_R \geq 0.5 \\ 0 & \text{for } C_R < 0.5 \end{cases}$$

with C_R, the contrast ratio, equal to C/C_T

where

C is apparent target/background contrast

C_T is threshold contrast.

This expression is a representation of Blackwell's data (1946). Threshold contrast on the visual axis is given by:

$$\log_{10} C_T = \frac{1.033}{\log_{10}\beta + 0.142} - 1.845 \quad (\log_{10}\beta > -0.142)$$

where β is angle subtended by the target at the eye (min) and threshold contrast off-axis by:

$$C_{T_{off}} = C_{T_{on}} \left[1 + \frac{0.803\,(\theta - 0.54)}{\beta^{0.4}}\right]$$

where

θ is angle off-axis in degrees

β is target subtense in minutes of arc.

This expression is fitted to data obtained by Taylor (1961).

No luminance term is included because, for an E-O system, display luminance was expected to remain near 10 foot lamberts.

The factor, P_1, which is computed in the manner described above, is not called a probability of detection although it is obviously related to detection, as it is defined by other workers. In fact, much of the methodology was adapted for the MARSAM II Detection submodel.

Recognition Submodel

The basic expression for recognition is

$$P_2 = \begin{cases} 1 - \exp\left\{-\left(\frac{N - 3.2}{11}\right)^2\right\} & \text{for } N \geq 3.2 \\ 0 & \text{for } N < 3.2 \end{cases}$$

where N = number of resolution elements across the target image. The expression for P_2 is based upon data obtained by Brainard (1965). These data were selected for the submodel because Brainard used an electro-optical system in his experiment. This is not a relevant argument for using the expression in direct visual models, but it is used, substituting visual resolution for E-O sensor resolution.

Confusing Objects Submodel

The effect of confusing objects in the field of view is accounted for by computing:

$$P_3 = \frac{1}{1 + \left(\frac{M}{29T^{0.93}}\right)^{1.29}}$$

where

M is the number of confusing objects in the field

T is the frame time.

This formulation was developed by Ryll, Cornell Aeronautical Lab, based on data collected by Boynton, et al. (1958).

Noise Submodel

The basic expression is

$$P_4 \begin{cases} = 1 - e^{-[S/N-1]} & S/N \geq 1 \\ = 0 & S/N < 1 \end{cases}$$

where

S/N is the ratio of input signal to display noise.

The GRC model's segmented structure was unique when it first appeared. The first three terms in the model were developed based upon laboratory data.

An early comparison with data collected by Oatman (1965) showed that the model prediction conformed to the TV observer data within the limits of experimental error for vehicle targets. Another comparison with data obtained from thermal imagery of personnel targets in Southeast Asia was also good.

In both validation studies, the majority of the crucial parameters are largely equipment-specific, which reduces the general applicability of the findings.

6.3.3 MARSAM II

The Multiple Airborne Reconnaissance Sensor [illegible] Model (MARSAM) was developed for the U.S. Air Force during 1967-[illegible] [illegible] [illegible], and Heitzmann, et al., 1968). MARSAM II is a [illegible] model and [illegible] described in terms of separate subsections. The segmented formula[illegible] was derived from the GRC model. MARSAM II is rep[illegible]ted as probably the [illegible]st

used current model (Greening, 1973) The model develops probability of detection (P_d) and probability of recognition (P_r) as single numerical values for a single encounter of one observer. Figure 6-9 shows the Visual Observer Model. The submodels are combined to produce P_d and P_r as follows:

$$P_d = P_{LOS} \cdot P^*_{ds} \cdot P^*_{d1} \cdot P^*_{d3}$$

and

$$P_r = P_d \cdot P_r^*$$

where

P_d = probability of detection.

P_{LOS} = probability of the existence of a line-of-sight to the target.

P^*_{ds} = a probability of fixating and dwelling upon a target element.

P^*_{d1} = a probability of detectability.

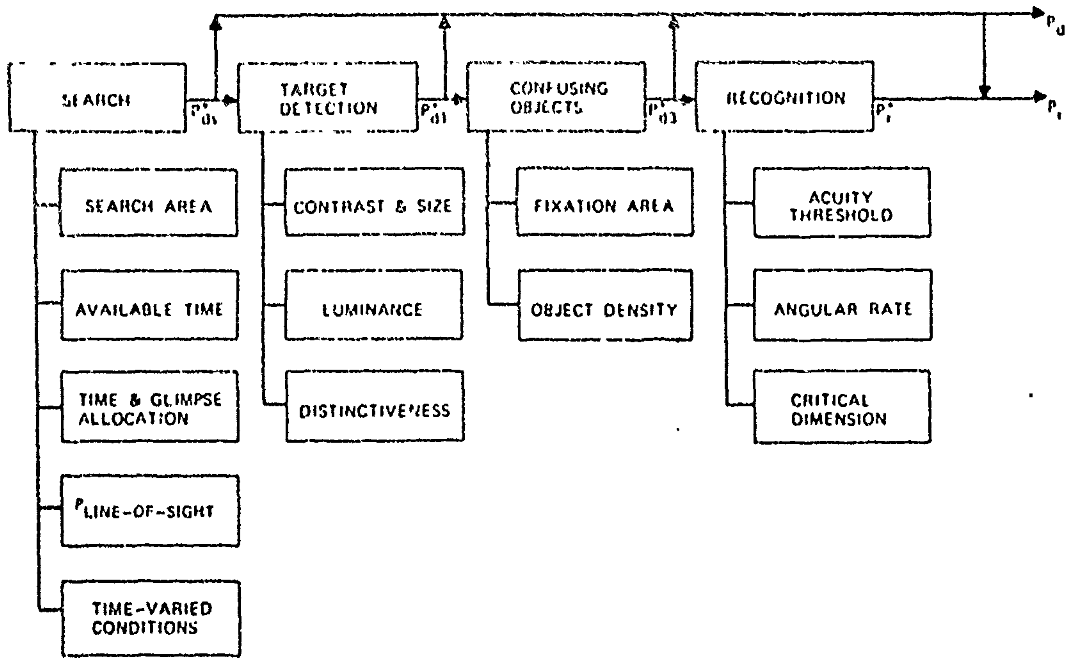
P^*_{d3} = a probability of confusion between target and non-target objects.

P^*_r = probability of recognizing a detected target.

P_r = conditional probability of detection and recognition.

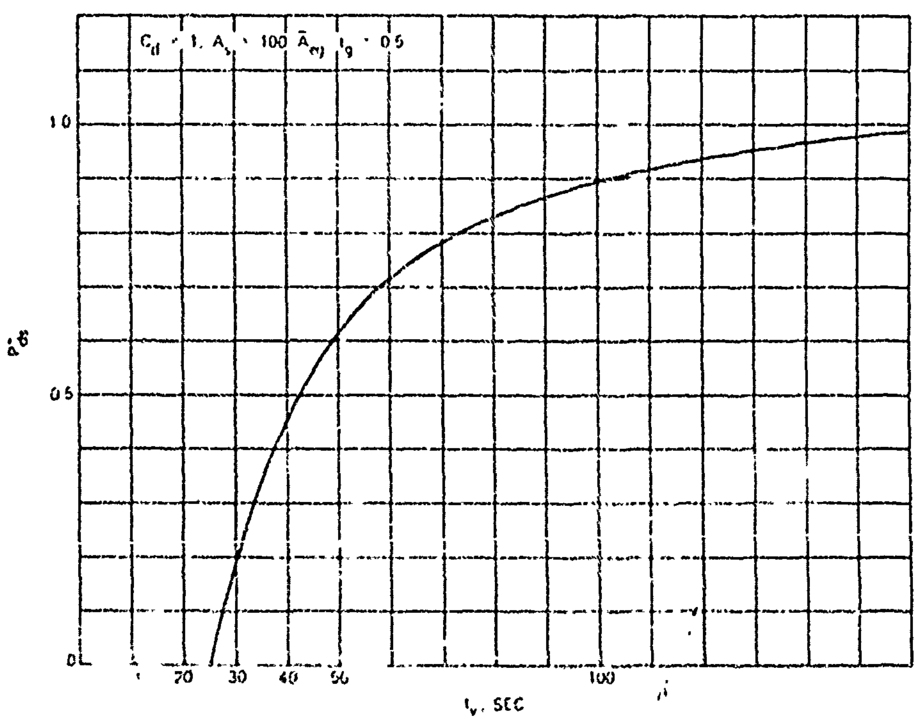
In the model P_d and P_r are numerical values for a single encounter.

The search submodel does not reference any data or theory. The authors state it to be principally an hypothesis (Schaefer, et al., Part II, page H-5). The physical area of search is described as the area around the nominal line-of-sight reduced by the minimum look down angle of the aircraft and the maximum meteorological range or terrain masking. This is further reduced by those areas in which targets are not likely (for example, a lake); it includes only the total area of all target elements, (thus assuming that all areas do not have to be searched). Finally, the probability of a line-of-sight to ground is averaged for three defined ranges usually near, medium and far. Search time is a function of aircraft speed through the search area and the size of the assumed aircraft to target offset. Search time and effective visual fixations (glimpses) are combined in a complex derived function that includes target size, contrast, target number, number of confusing objects and a five degree cone of visual fixation per search area (Figure 6-10).



SOURCE: GREENING, 1973

Figure 6-9. MARSAM II - Observer Model Structure



SOURCE: GREENING, 1973

Figure 6-10. Probability of Fixating and Dwelling on a Target as a Function of Available Search Time (MARSAM II)

The MARSAM II descriptive literature calls their target detection submodel a "Target-Element Size and Contrast Submodel," but the output is a probability that the target element is detectable. The Detection Submodel is patterned after GRC Model A, which in turn is based upon Blackwell's laboratory data. The Blackwell data are adjusted by shifting the threshold contrast axis by 0.75 log units, to account for degraded performance in non-laboratory situations. This degradation was selected on the basis of a discussion by Davies (1965) of the U.K. Royal Aircraft Establishment (RAE).

The confusing objects submodel is derived from that of Boynton (1958). Ryll (1962), Section 6.3.1, developed an algebraic expression for the Boynton data, which is used in MARSAM II. The number (density) of confusing objects in the target area is given as an input to the model.

Target recognition, for both the visual and E-O models, is based on the formulation used in the GRC model. Both models use Brainard's data of 3.2 resolution lines through the target for average recognition.

The validity of MARSAM II model has not been reported as having been evaluated in field tests. The detection, recognition and confusing object [illegible]dels are, as noted, based upon laboratory data. The search submodel [illegible]re hypothesis and the assumed relationships between submodels a[illegible] proven.

6.3.4 [illegible]

[illegible]pment of a visual target acquisition model was one objective of the [illegible]2 (Joint Task Force [illegible]) test program. W. H. Bradford (1966), prepare[illegible] [illegible]e first published description of VISTRAC.

Th[illegible] optical [illegible]roperties [illegible] the eye during search were drawn primarily from Lamar. Bradford postulated that the distribution of acquisition time was continuous. He [illegible] defined a quantity called "rate of target acquisition," and tre[illegible] it as a continuous function of time, one which has a derivative at all times, again following Lamar. This treatment of the search process leads to a cumulative probability function.

The continually varying angle between line-of-sight and line-to-target is [illegible]mpared and used to evaluate instantaneous rate of acquisition.

The three constants in the Bradford model were selected to match data from a s[illegible]gle target in the Boeing motion picture simulator study, done under [illegible] 2 sponsorship (Bradford, 1966). Validation studies have used the [illegible]-2 field test data (JTF-2, Test 3.1, Annex C). The usual concept [illegible]rget acquisition as detection, recognition and identification w[illegible] not used in the model. The rate of acquisition probabilities

is for pre-briefed targets. There is no resolution term in the model. The probability of acquisition is presumed to include detection, recognition and identification of a target.

The basic expression for target acquisition probability is:

$$P_A(\text{cum}) = 1 - \exp\left\{-k\int_{t_u}^{t_m} (C_T-b)^m \, dt\right\}$$

where

$P_A(\text{cum})$ = cumulative probability of acquisition (i.e., detection, recognition and identification)

t_u, t_m = integration limits - time unmasked t_u, to time masked, t_m, (limited by aircraft structure)

C_T = contrast ratio or apparent contrast/threshold contrast

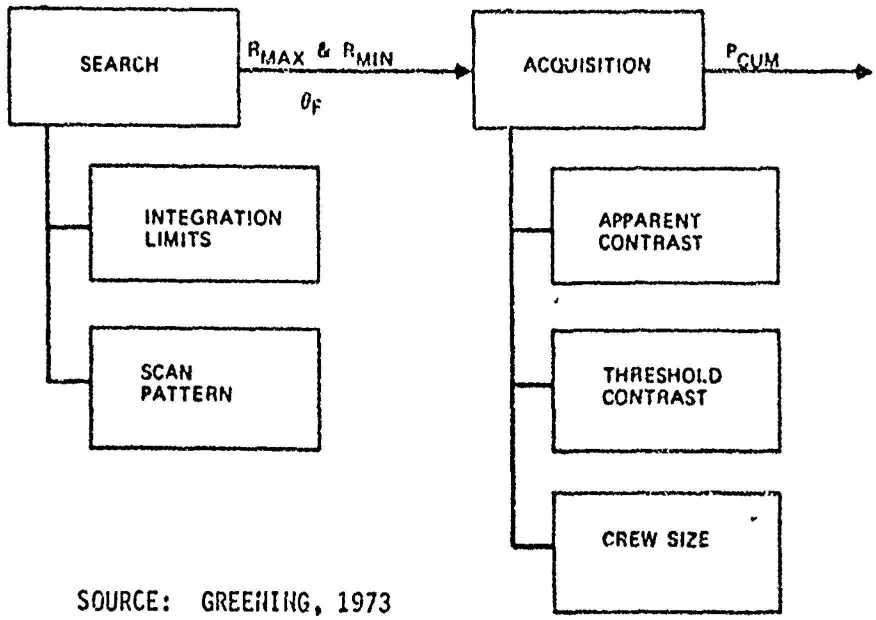
k = a constant, related to task loading. Empirically evaluated from the JTF-2 data at 0.009 to 0.018 depending on aircraft and task.

b = a constant - the minimum CR, below which no acquisition occurs. Empirically determined - about 0.62.

m = a constant - empirically determined - about 1.9.

The structure for the VISTRAC Model 5 is shown in Figure 6-11. VISTRAC models a straight, level flight over or past a target at a known location. The probability of acquisition is cumulative from maximum range to a minimum, based upon a visual lobe which is assumed to scan in a preset, continuous (i.e., non-glimpse) fashion. Acquisition at any time is determined by the distance to the target, the scan pattern, and the apparent size and contrast of the target.

The maximum range R_{max} of the integration limits in the model is set by the unmasking of the target. This can be a predetermined range (an input) or a computed mask angle which can be compared with the instantaneous look down angle. Integration can also begin when atmospheric and inherent contrast yields a contrast ratio greater than a set minimum below which no acquisition occurs. Minimum range R_{min}, the end of integration, is an input determined by aircraft structure. The visual scan pattern also depends on aircraft structure, aircraft speed and aircraft seat (front or rear) in a tactical aircraft.



SOURCE: GREENING, 1973

Figure 6-11. VISTRAC - Observer Model Structure

The contrast ratio term is based upon Lamar's concepts. The analytic expression for visual contrast threshold is derived from laboratory data as cited by Lamar. Apparent contrast depends upon the inherent contrast between target and background as modified by effects of the intervening atmosphere. Contrast threshold as defined earlier (paragraph 6.2.3.1) is:

$$C_T = 1.55 + \frac{15.2}{\beta^2} \quad \text{for} \quad \theta \leq 0.8°$$

and

$$C_T = 1.75\ \theta^{1/2} + \frac{190}{\beta^2} \quad \text{for } \theta > 0.8°$$

The VISTRAC model is based upon Lamar's treatment of detection, and represents contrast thresholds of a uniform target against a uniform background. The results are presented as a curve of probability as a function of contrast ratio. At this point, Bradford's treatment departs from Lamar's. Bradford presumes an exponential form for probability vs. contrast ratio and assumes that the value of this expression, at any contrast ratio, is also a function of time. He then integrates the exponential over time, for predetermined values of θ and β leaving the constants, M and k, to be evaluated empirically.

The evidence of validity in Bradford's development of the search term depends upon the appropriate choice of data upon which it is based.

Here the difference between Lamar's and Bradford's objectives becomes crucial. Lamar (and the OEG) were working on the problem of air-to-sea search on an unstructured background. Detection of a single, contrasting area in a formless search area is the objective. Bradford, however, was modeling search for targets on the ground with numbers of easily detectable objects. Here target acquisition includes recognition and identification and involves resolution of some elements of the target shape or pattern. Thus, the Lamar approach to search is not necessarily appropriate in this situation.

The VISTRAC model was developed in conjunction with JTF-2 field tests. The three constants in the expression have been evaluated, at least in part, from field data. While the model approach is analytic, the use of field data as constants and modifiers is an empirical touch.

The quantity "b", which represents a contrast ratio below which acquisition probability is zero, lies between 0.43 and 0.65 determined on the basis of the laboratory data. The exponent "m" in the region 1.5 to 2.0 was determined from the laboratory data. Selection of values for "b" and "m" and evaluation of "k", the multiplier, were done by reference to data from the field or from motion picture simulation in JTF-2 films. Values of b = .62, m = 1.9 and k = .0158 were chosen to optimize the fit to simulator data on a single target. The value of "k" (which is called a "task loading factor") was modified in field trials (e.g., k = .018 for the RF-4C aircraft and .003 for A-4B aircraft). Validation data have also been reported but no quantitative estimate of the relationships is included (personal communication, J.A. Keller, Falcon Research, March 1974). Figures 6-12 and 6-13 are two examples of field test data compared with model predictions; the first shows a poor fit, the second a "good" prediction. In general, the quality of the JTF-2 physical data (see Section 6.4, following), Bradford feels, has limited the utility of these comparisons (JTF-2, Test 4.1, Annex C). Because this model contains some empirical field data, it is unfortunate that it has not been further evaluated.

6.3.5 Autonetics Model

The present "Autonetics Model" was originally developed in 1959 (Greening, 1973). It has been improved and updated in later versions, based primarily on visual simulator data. As later derived, the model assumes that the probability of a single glimpse at a target is exponentially related to the resolution of the sensor (eye) and the required resolution to detect the target thus:

$$P_{SG} = P_L \; e^{-(r_s/r_o)^2}$$

and

$$P_{CUM} = 1 - \pi_i \; (1 - P_{SG_i})$$

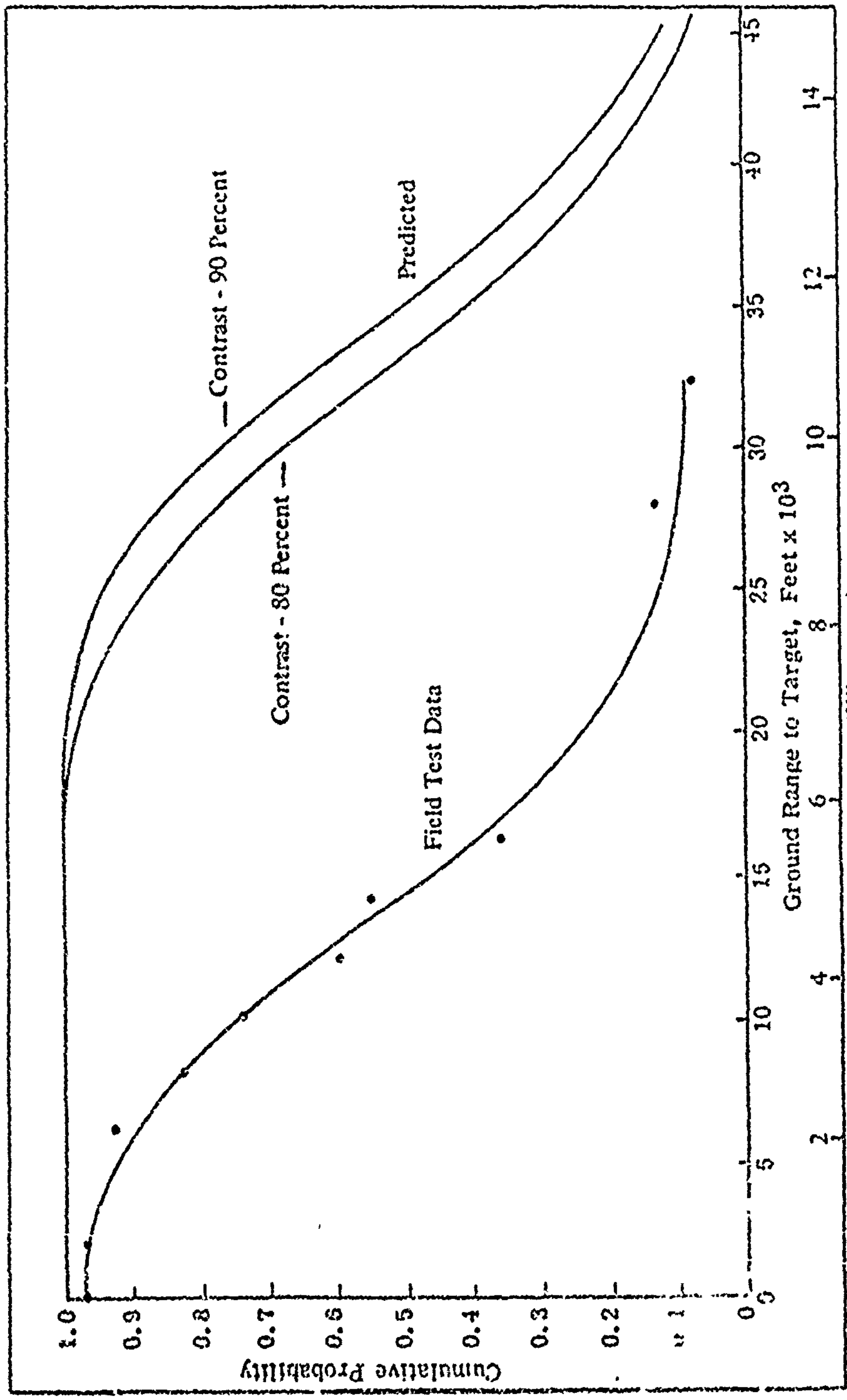


Figure 6-12. Probability of Acquisition-VISTRAC Model vs Field Tests (East Course)

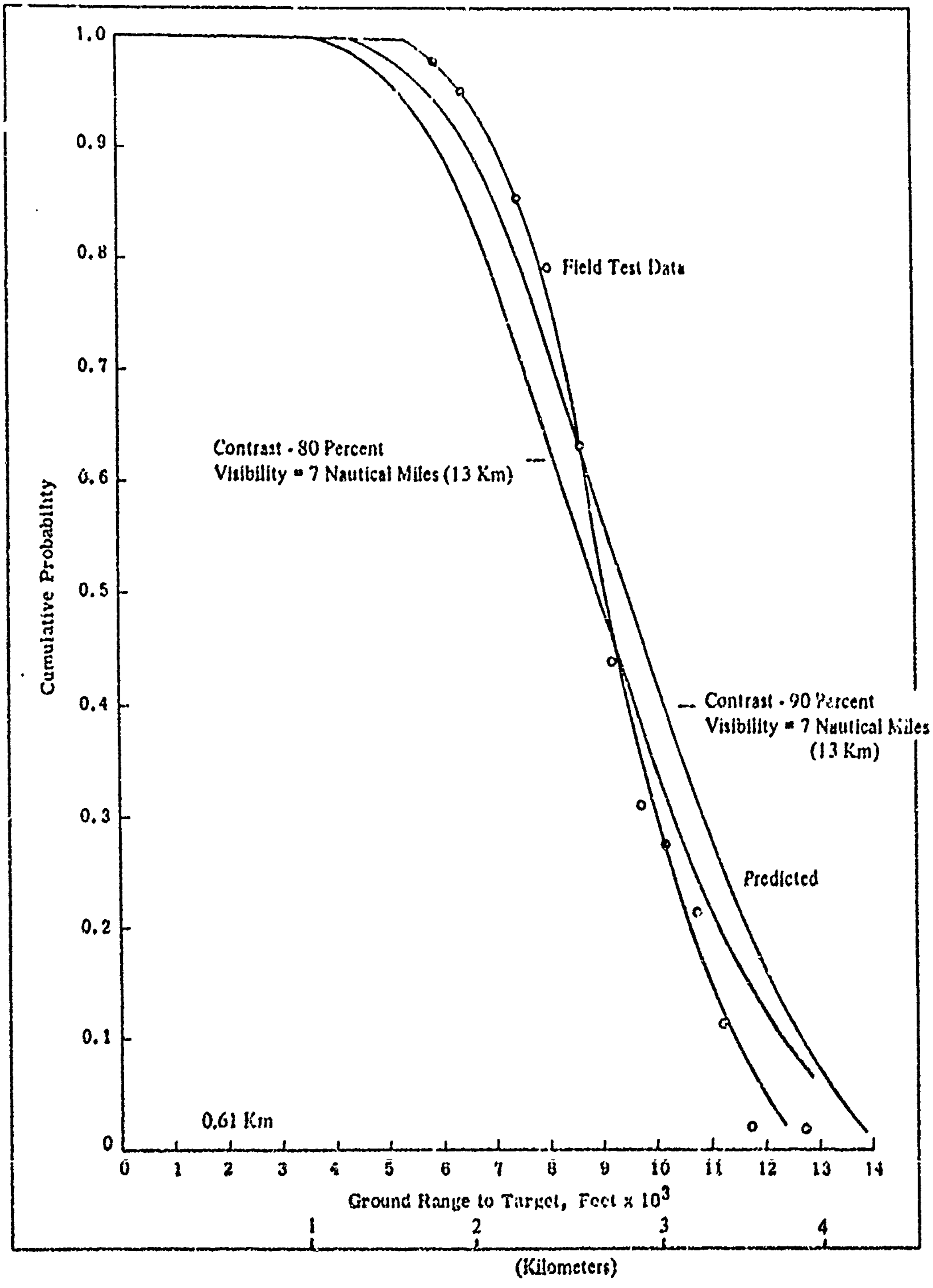


Figure 6-13. Probability of Acquisition-VISTRAC Model vs Field Tests (West Course)

where

P_{SG} is single glimpse probability

P_{CUM} is cumulative probability after i independent, consecutive glimpses

P_L is probability of looking at (fixating) the target, (an input).

r_s is the resolution capability of the sensor (eye)

r_o is the resolution required to detect or recognize the target.

Figure 6-14 shows the general structure of the Autonetics model.

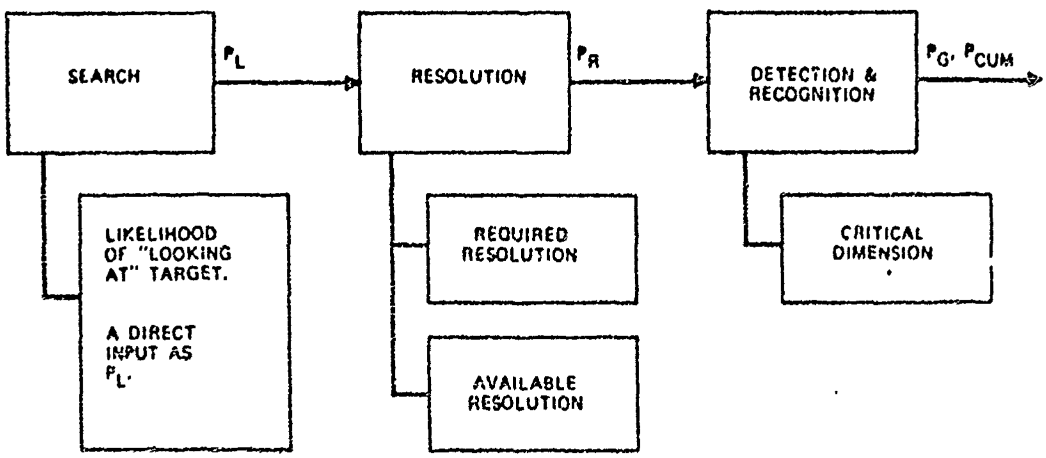


Figure 6-14. Autonetics Model - Observer Model Structure

The search submodel, P_L is used as a given factor. Its derivation depends upon the tactical situation (Greening and Wyman, 1970) rather than the "visual-lobe" approach. It is assumed that the observer is searching the real world for known targets on which he has been briefed. His search technique reflects this situation and thus the probability of looking at the target is derived as a function of the number of objects similar to the target in the search area. Thus:

$$P_L = \frac{1}{N + 1}$$

where N is the number of target-like objects in the area to be searched. The resolution sub-model is as follows:

$$P_r = e^{-(r_s/r_o)^{2K}} \qquad K = 1 \text{ for } r_s/r_o > 1$$

$$K = 2 \text{ for } r_s/r_o \leq 1$$

where

P_r is probability of resolving the target

r_s is linear resolution capability of the sensor (eye)

r_o is required linear resolution for detection/recognition

The resolution capability of the eye is modeled in two steps:

$$r_s = \frac{a_e}{(C - C_T)^{1/2}}$$

and

$$a_e = \frac{2}{[1 + (\log_{10} B + 3)^2]^{1/2} - 0.8}$$

where

a_e is linear resolution of the eye at 1.0 contrast, in minutes

C is apparent target to background contrast

C_T is threshold contrast

B is average scene luminance in foot lamberts.

Required resolution is determined from the geometry of the situation and the detection/recognition level required, thus:

$$r_o = \frac{A_t^{1/2}}{n_o}$$

where

A_t is area subtense of the target

n_o is the number of resolution elements across the narrow target dimension required for detection or recognition.

The probability of detection/recognition is determined from the simple expression:

$$P_G = P_L P_r$$

where

P_L is probability of "looking at" the target determined from search submodel.

P_r is probability of resolving target determined from the resolution submodel.

The value of P_G can represent a probability of detection or recognition or identification, depending upon the value of n_o used. Typically, $n_o = 2$ is used for detection, and $n_o = 8$ for recognition.

The cumulative probability of detection and recognition is developed by computing a P_G for each fixation interval from initial visibility range to the desired minimum range. P_G generally increases because both contrast and target area increase as range-to-target decreases. The cumulative probability is then computed from:

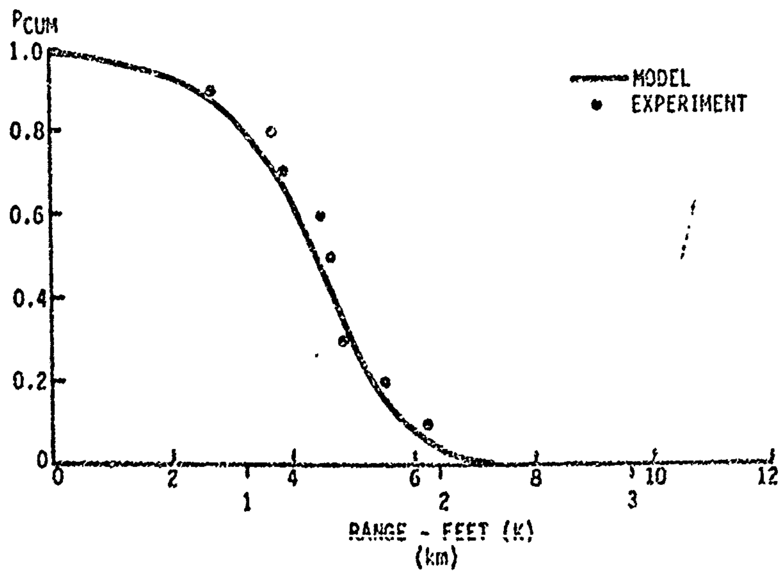
$$P_{CUM} = 1 - \pi_i (1 - P_{G_i})$$

where

P_{CUM} is cumulative probability from the first to the present glimpse.

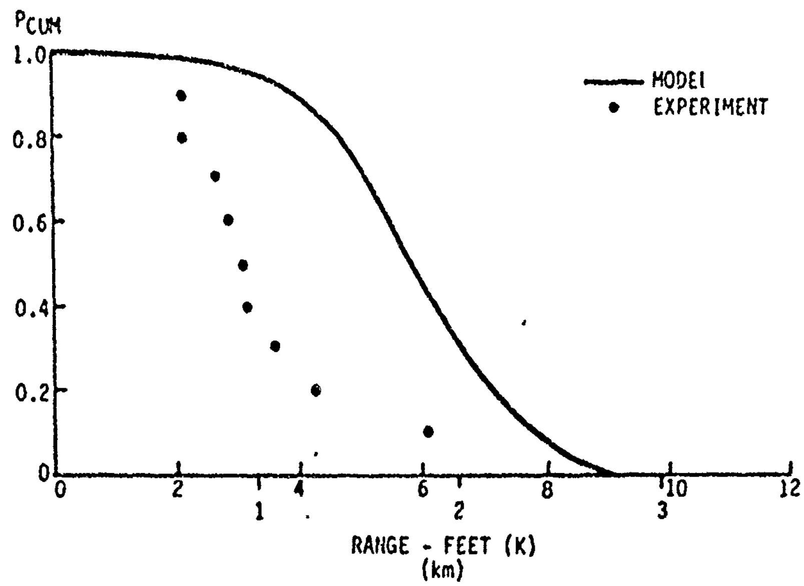
P_{G_i} is the value of P_G at the i^{th} glimpse.

One major validation study using a motion picture simulation has been conducted (Greening and Wyman, 1970). The results showed some agreement with the simulation data, a product-moment correlation of + .53, significant at the 0.001 level of confidence was obtained between theoretical (model) and empirical (simulator) recognition ranges. Figures 6-15 and 6-16 show examples of good and poor predictions from this motion picture simulator validation study.



TARGET: STORAGE TANKS
SOURCE: GREENING AND WYMAN, 1970

Figure 6-15. Cumulative Recognition Probability as a Function of Range for Experimental and Theoretical Data



TARGET: HIGHWAY OVERPASS

SOURCE: GREENING AND WYMAN, 1970

Figure 6-16. Cumulative Recognition Probability as a Function of Range for Experimental and Theoretical Data

6.3.6 British Models

The British Royal Aircraft Establishment (RAE) has sponsored several programs of target acquisition modeling. Early work was conducted by Heap (1962a, 1963b, 1966, Heap and Foley, 1961). Currently these early models are not used, since they were found to be optimistic (Greening, 1973). Recent British modeling has been under leadership of E.B. Davies, who reported that there is no set RAE model, rather each specific situation was modeled as required (Greening, 1973). In general, the British models are based upon the visual lobe concept and use the analytic-constructive approach.

Recent RAE modeling is typified by the work reported by Overington (1972). The RAE models have refined the single glimpse and visual lobe concepts to account for:

1. Near visual threshold targets which do not necessarily lead to a cumulative detection probability of 1.0 (Davies, 1965).

2. Elimination of "wasting" detection lobe areas which are outside the desired search area (Davies, 1968).

3. Realistic approximations of the visual lobe shape as it intersects with the ground (Smith, 1968).

4 Modification of models to fit field data (Davies and Smith, 1969).

5 Use of target objects differing from the typical model of circle or square (Davies, 1971).

A recent sophisticated model was reported by Overington (1972) at a NATO/AGARD symposium on air-to-ground target acquisition. It considers the physical properties of the eye as part of the total target detection process. This part of the model fits the Blackwell laboratory data for visual search rather well. The complete model also includes a constant to account for observer motivation, although precise definition or description of the term is not included.

A second British group involved in target acquisition modeling is at the Defense Operational Analysis Establishment, led by G.P. Owen. The most recent and up-to-date model is VISTARAQ, described by Owen as a "second generation" development. The model report is classified and thus not available for this publication; however, Greening (1973) has summarized the general format. It, too, uses the analytic approach:

The basic single-glimpse probability function is derived on the assumption that the "stimulus value" of a target is given by:

$$S = \frac{\log C/C_o \cdot \log B/B_o \cdot \log n/n_o - K_T}{\sigma}$$

where:

C is target/background contrast

B is scene luminance

n is number of affected visual retinal receptors, related to target apparent size

C_o, B_o, and n_o are threshold values

σ, K_T are constants.

Recognition in VISTARAQ is handled by computing detection performance for the "critical feature" of the target object.

The "number of receptors," n, is determined by setting up a rectangle of area equal to the target and projecting its image onto the retina. Corrections are made for decreasing density of receptors in the non-foveal area for large targets and for the spread of small images (less than 5 arc minutes) due to optical limitations of the eye.

The VISTARAQ model also incorporates a search area factor ($F = [(a/A)^{1/2} - a/4A]^2$ with a = visual lobe solid angle and A = search zone solid angle) and a probability of line-of-sight factor (PL). The resulting cumulative probability is:

$$P_N = 1 - (1 - F \cdot PI \cdot P_g)^N$$

when P_g, the single glimpse probability, is given by

$$P_g = 0.5 + \frac{1}{\sqrt{2\pi}} \int_0^x e^{-\frac{S^2}{2}} \, dS$$

where N is the number of glimpses, and S is as defined above.

VISTARAQ has been validated against laboratory detection experimental data and field test results (Greening, 1973). Extension to operational situations has not been reported.

6.3.7 Franklin and Whittenburg Model

Under U.S. Army Human Engineering Laboratory sponsorship, Franklin and Whittenburg developed a relatively simple operational model. The model is one of the first to be based on empirical field data. It is designed to predict visual air-to-ground target acquisition of tactical targets under daylight conditions. Army air observers are characterized under relatively slow, low altitude conditions. "The model should not be used to predict at altitudes below 100 feet (30.5 meters) and above 500 feet (152 meters) and at speeds greater than 150 miles per hour." (Franklin and Whittenburg, 1965, p. 69).

The model is characterized by (1) reliance on field data in preference to laboratory data, (2) reduction of the number of variables as far as possible without undue restriction in generality or accuracy, and (3) simple format. It is based upon an extensive literature review. However, the model is primarily derived from data from an earlier field study by Whittenburg (1959). In this study, observers were flown at low altitude (61 meters) and low speed (100 mph) past a number of targets or target groups with nearest slant range between 74 and 310 meters.

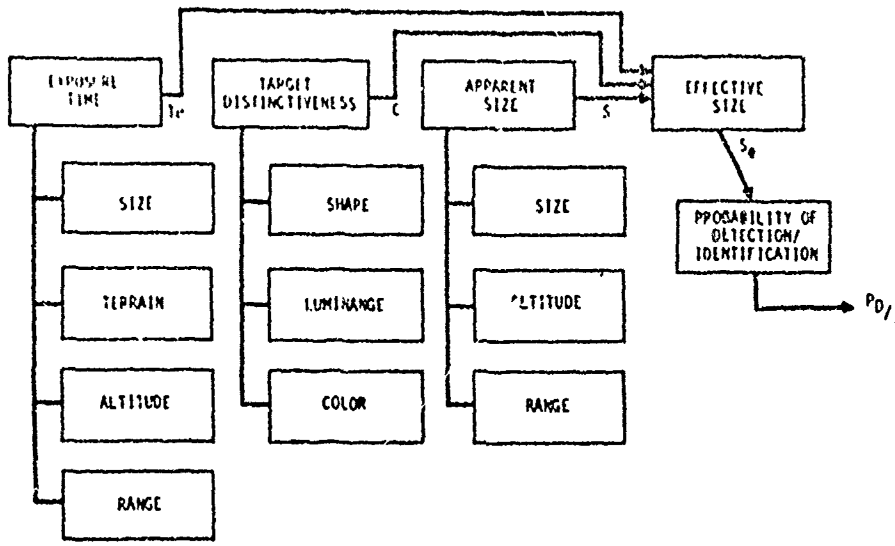
The variables selected for incorporation in the model are (1) target size, (2) target shape, (3) luminance contrast, (4) clutter, (5) terrain, (6) altitude, (7) range at closest approach, and (8) speed of observer platform. These variables were combined into three composite variables:

1. Apparent size, combining size (in square mile), altitude and range

2. Target distinctiveness, combining shape, contrast and color

3. Exposure time, combining size, terrain, altitude, and exposure time.

Two of the composite variables, apparent size and exposure time, are confounded to some extent. Figure 6-17 shows the general model structure. The variables are mathematically defined as follows:



SOURCE: GRECHING, 1973

Figure 6-17. Franklin and Whittenburg Model Structure

1 Apparent size,

$$S = A\left(\frac{K}{D}\right)^2$$

where: A is target area

D is slant range

2 Target distinctiveness, $C = f\ (C_b, C_c, C_f)$

where: C_b is related to luminance contrast, C_c is related to color contrast, and C_f is related to form contrast. Actually, C was judged from target photos and took a value from 1 (lowest) to 12 (highest).

3 Exposure time, $T_e = \sqrt{T/5}$ for $T < 5$ seconds; $T_e = 1$ for $T \geq 5$ seconds.

T is measured time from first availability of the target (un-masked; within ±45° of beam of the aircraft; subtends ≥ 5 square mils) to last availability (same criteria).

$S_e = f(S\ \ C\ \ T_e)$ where S_e is a quantity called "effective target size". S, C, and T_e are defined above.

"Probability of Detection/Identification" is then determined from curvefitting, to be given by:

$$P_{D/I} = 1 - \exp(-.0167\ S_e)$$

$P_{D/I}$ is a different term than is used in other models. While not precisely defined by Franklin and Whittenburg it is most nearly equivalent to Bailey's concept of P_R, (probability of recognition), the conscious decision that "there is the target." In operational terms $P_{D/I}$ can represent a decision by the observer to attack a target.

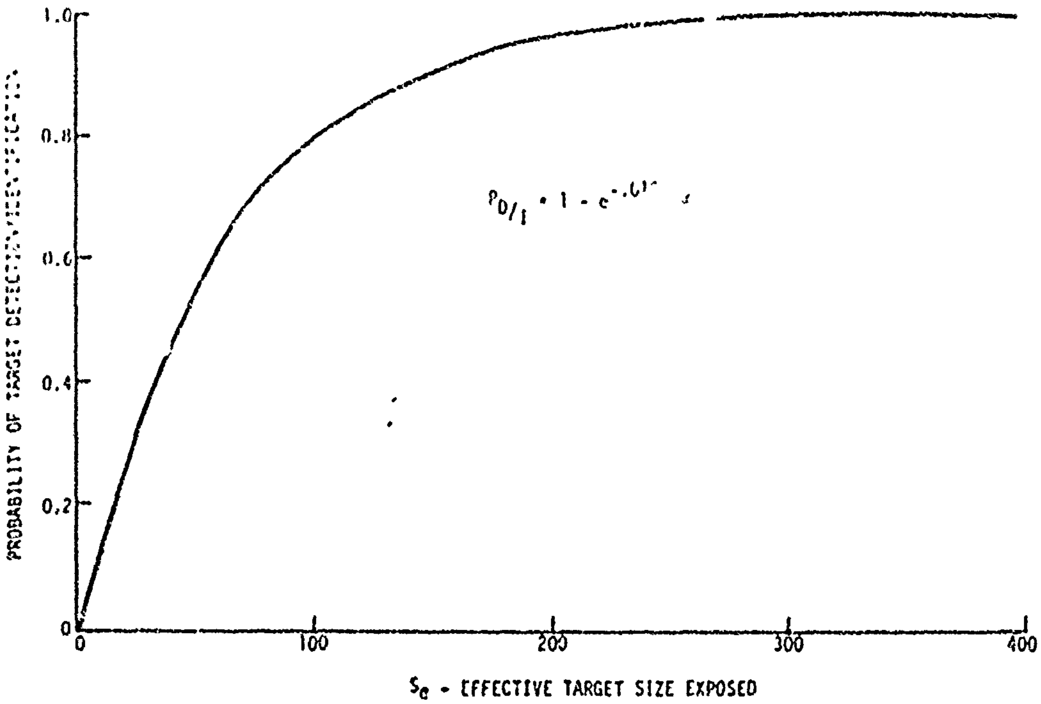
The Franklin and Whittenburg model is analytically simple, involves few variables, and is based upon field data. It omits such variables as target/background contrast, scene luminance, and meteorological visibility. The model limits applicability to conditions in which sensitivity is not great; e.g., moderate contrast targets in clear, daylight conditions.

The form of the model is unique. It does not lend itself to direct comparison with most others. It is a "fly-by" rather than a forward looking model. It provides a single probability for an encounter, not cumulative. There is intermingling of detection/recognition/identification in the output. The "Target Distinctiveness" term is an overall judgmental factor.

This model has not received the attention that it merits. The Franklin and Whittenburg model has been used in the extensive and well documented Stanford Research Institute (SRI) CRESS-SCREEN model of battlefield reconnaissance and surveillance (Laurence, 1972). In this SRI model more extensive analytic-constructive expressions for the "apparent size" and "apparent contrast" terms are developed. The final model term $P_{D/I}$, probability of detection/identification, is the identical Franklin and Whittenburg formulation.

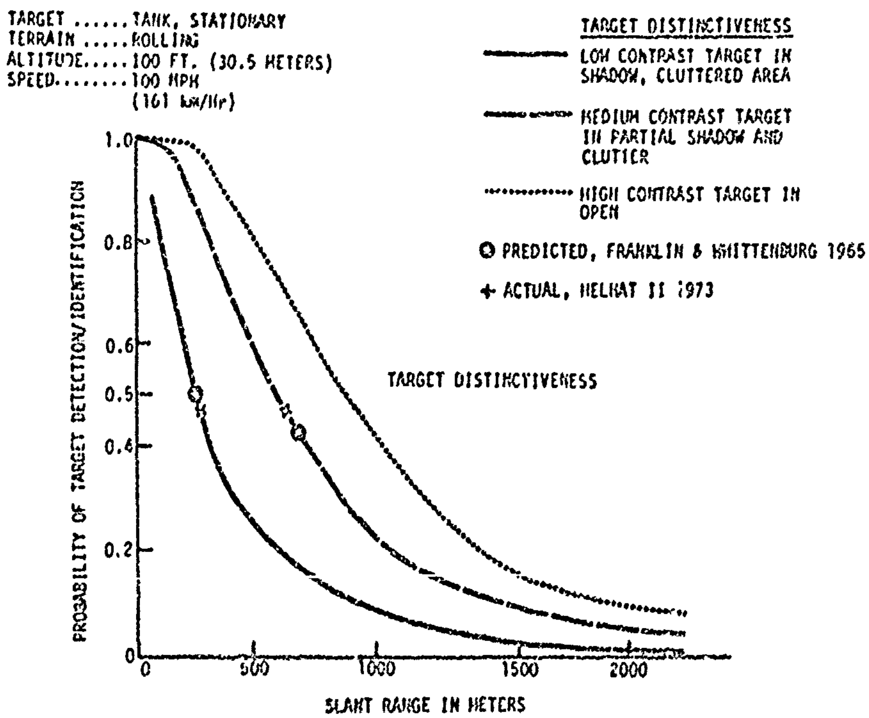
Figure 6-18 presents the probability of target detection/identification as a function of target size exposed to the observer.

The model is based upon field data, and thus in part derives its validity from that field data. It should be able to predict similar field data with relative accuracy. This is indeed the case. Figure 6-19 compares the obtained probability of target detection/identification on a series of helicopter scout crew/observer target detection flight tests with that predicted by the Franklin and Whittenburg model; the results agree within one percent (U.S.A. HEL TN 5-74, 1974).



SOURCE: FRANKLIN AND WHITTENBURG, 1965

Figure 6-18. Probability of Target Detection/Identification as a Function of Effective Target Size Exposed



SOURCE: HEL TN 5-74

Figure 6-19. Helicopter Observer Field Test Data Compared with Franklin and Whittenburg Model Prediction

6.3.8 SRI-CRESS/SCREEN Model

The Stanford Research Institute (SRI) observer model was part of a comprehensive model originally called CRESS (Combined Reconnaissance, Surveillance and SIGINT), which modeled the entire information collection and processing system in the Army. A later modification of the modeling effort has been called SCREEN (SRI Counter-Surveillance Reconnaissance Effectiveness Evaluation). The CRESS/SCREEN Visual Observer Model is based upon the Franklin and Whittenburg model. It requires, as inputs, information about the targets and backgrounds, search geometry, and environment, and generates probabilities of detection, recognition and identification, as well as non-detections, misrecognitions, etc. Because of the way in which the visual observer model is embedded in CRESS and SCREEN, it is not easy to isolate the inputs and outputs which "belong to" the observer model (Greening, 1973). However, the SRI work is generally well documented, so the model is accessible to the interested reader (Laurence, 1972).

The visual model structure is shown in Figure 6-20. The similarity to the Franklin and Whittenburg is obvious. Apparent contrast (C_A), effective time (T_E) and apparent size (S_A) are conceptually similar to the Franklin and Whittenburg formulations of apparent size (S), target distinctiveness (C), and exposure time (T_E). It has the same essential limitations of low speed and altitude.

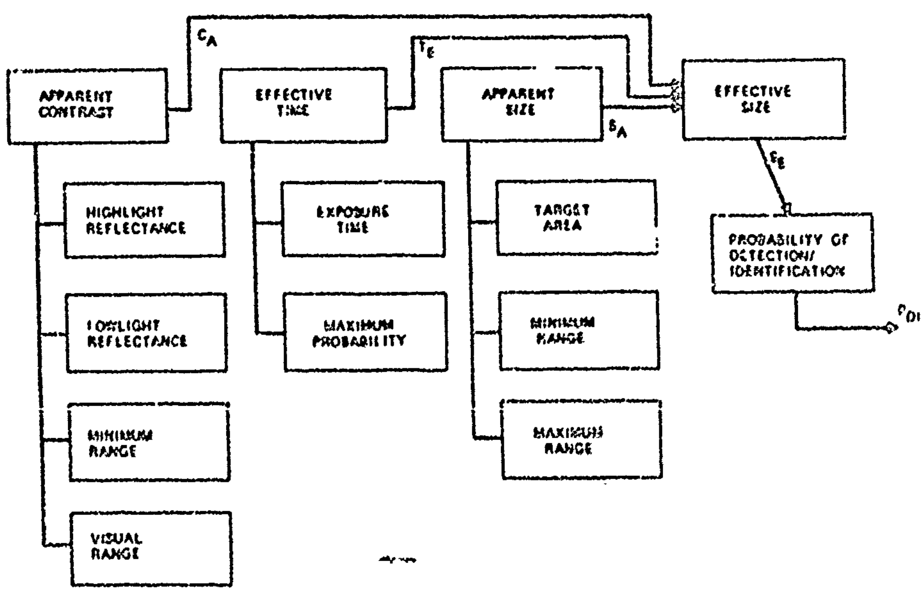


Figure 6-20. SRI CRESS/SCREEN Model Structure

Apparent Size. The apparent size of the target is expressed in terms of the angular subtense of a square object of the same area as the target, viewed at the geometric mean of farthest and closest slant range. The expression is:

$$S_A = K \left\{ \frac{A}{2} \left(\frac{1}{R_O^2} + \frac{1}{R_M^2} \right) \right\}^{1/2}$$

where

A is target area

R_O is the slant range at the moment of closest approach, a function of altitude and lateral offset

R_M is the slant range at first visibility, a function of target size, meteorological range and altitude, but limited by the assumption of visual observation out the side of the aircraft limited to 45 degrees fore and aft of the beam. The range vs. size function is a lookup table, based on National Defense Research Council Nomographs, for an assumed illumination level, sky/ground ratio (Duntley, 1946). The resulting threshold range is then degraded for reduced meteorological visibility.

Apparent Contrast. The "contrast" term used in CRESS is somewhat different from most. The output, C_A, is obtained from:

$$C_A = \frac{C_T}{C_T - \left(C_T - 1\right) e^{-(KS_R/V_R)}}$$

where

C_T is intrinsic "contrast," R_H/R_L

R_H is highlight reflectance, R_L is low-light reflectance (For camouflaged targets, $C_T = 0.9 + 0.1\ (R_H/R_L)$.)

S_R is slant range at nearest approach

V_R is meteorological range, an input.

When CRESS was adapted to SCREEN, the intrinsic contrast term was modified to permit handling of non-uniform targets against non-uniform backgrounds. Non-uniform effects on the computed value of C_T are included first, by averaging luminances of sub-areas to get an average, or far-field, contrast, and second, by deleting sub-areas which have below-threshold contrast with the background.

The averaging is accomplished as follows:

$$C_T = \frac{\bar{R}_H}{\bar{R}_L} + \sum_{i=1}^{4} \frac{1}{P_i} \sum_{j=1}^{4} B_j \left[\left(\frac{R_H}{R_L} \right)_j - R \right]$$

where

$$\bar{R}_H/\bar{R}_L = \max \left(\frac{R_B}{R_O}, \frac{R_O}{R_B} \right)$$

from

$$R_O = \frac{1}{A} \sum_{i=1}^{4} R_{Oi} A_i$$

$$R_B = \frac{1}{P} \sum_{i=1}^{4} R_{Bi} P'_i$$

with

A, P the total area and perimeter of the object

A_i is the area of i^{th} region

P'_i is 1/2 the perimeter of the i^{th} region

R_{Oi}, R_{Bi} are object and background reflectance in i^{th} region

$\left(\frac{R_H}{R_L} \right)_j$ is highlight and low-light reflectance across the j^{th} boundary of the i^{th} sub-region

P_i is the perimeter of the i^{th} region

B_j is the length of the j^{th} segment of the boundary of the i^{th} region.

R is $\frac{\bar{R}_H}{\bar{R}_L}$ if B_j is between object and background and

1 if B_j is within the object.

The deletion of sub-areas which blend with the background is accomplished by testing each object/background region contrast against a threshold value. If it is below the threshold, then the area, A_i, in that region is deleted from the value of A, the total target area, in the apparent size computation.

The corresponding term to apparent contrast in the Franklin and Whittenburg model is a judgemental "target distinctiveness," C, running from 1 (lowest) to 12 (highest). The values of C_T can run from 1 (for zero contrast) to infinity (for zero-level low-light). C_A can take any

value from 1 (for $V_R = 0$) to C_T (for $V_R = \infty$). It is not apparent that C_A computed in this way will bear any relationship to "C", the Franklin and Whittenburg "target distinctiveness" term. It is used interchangeably with it in the Probability of Detection/Identification Submodel discussed later, however.

<u>Effective Time</u>. The quantity T_E, called "effective time," is not a time measure per se, but a multiplier, between 0 and 1 in value, reflecting performance degradation where time is "insufficient." It is determined from

$$T_E = \begin{cases} P_M \sqrt{T_{0/5}} & \text{for } T_0 < 5 \text{ seconds} \\ P_M & \text{for } T_0 \geq 5 \text{ seconds} \end{cases}$$

where

P_M is maximum probability given ample time, an input from judgment of experienced observers

T_0 is total exposure time, and is derived from airspeed, an input, and the distance traveled while the target is in view, a function of lateral offset, threshold range, and the ±45° field-of-view limits.

<u>Effective Target Size</u>. This submodel is simply a multiplicative merging of the three quantities derived above:

$$S_E = S_A \cdot T_E \cdot C_A$$

As has been seen, S_A is in milliradians and is fixed for one pass by a given target; T_E is a multiplier with a value of P_M (which is always ≤ 1.0); C_A is a contrast-related quantity with values between 1 (for no contrast) and infinity. This quantity is similar to the S_E used by Franklin and Whittenburg, except that C_A is differently valued.

<u>Probability of Detection/Identification</u>. The CRESS Visual Sensor Model provides a single probability figure as a function of S_E, using:

$$P_{D/I} = 1 - e^{-0.0167\, S_E}$$

This form is identical to that developed by Franklin and Whittenburg. The meaning of a "probability of detection/identification" is not defined, but is similar in concept to "recognition."

The value for $P_{D/I}$ is used as part of the total CRESS/SCREEN model. This model of a tactical situation involves a large number (750) of target objects, up to 40 target groups, information about weather, cloud cover, camouflage and tactical dispositions. Based upon these and other tactical considerations as well as random probabilities, both probabilities of

recognizing and missing targets can be computed. Shadow effects on probability of target detection are also computed. These detailed considerations are beyond the scope of this sourcebook; however, see Laurence and Payne (1971).

Since this SRI visual target acquisition model is based upon that of Franklin and Whittenburg it should have much the same validity and predictive power. The derivations of apparent size and apparent contrast are based upon the more usual analytic-constructive methods. As noted these values are not necessarily equivalent in the two models although they intuitively appear to be so. Reports of field tests of the SRI visual detection models are not available. Thus, while the approach seems logical, reports of validity are not available.

6.3.9 Boeing Model Concepts

The Boeing model was developed during the early 1960's by J. D. Gilmour and P. L. Emerson. The general formulations were published in an external report in 1965. While the model has been used internally, further documentation has not been published. Some additional conceptual details are available however (Gilmour, 1972).

The conceptual scheme underlying the Boeing modeling effort is that of an "expected value, decremental, dynamic model." Expected probability of target acquisition is computed at discrete intervals during a pass over the target area, based on an ideal performance, degraded by the conditions which depart from ideal. Gilmour lists four major-sequential elements needed to successfully predict target acquisition performance:

1. Geometric Intervisibility - Geometric line-of-sight and compatibility between available field-of-view and the ground area containing the target,

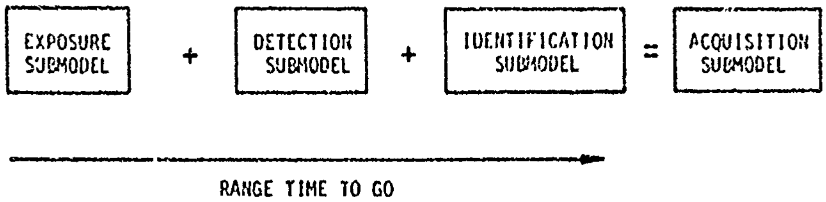
2. Visual Target Availability - Providing a minimum visual presentation of the target element to the observer,

3. Real-Time Search - Successful visual sampling of the target element from all of the dynamic scene elements present, and

4. Discrimination and Decision - Requiring detail discrimination to a level necessary to satisfy the observer's pre-stored "target" definition.

These requirements are cumulative and sequentially-dependent. Certain groups of variables will determine whether each particular sequential requirement is met. The categories of variables are not necessarily exclusive, Gilmour states, since some variables operate on different requirements in more than one way. Thus, the operational performance criteria of the acquisition model can be specified in terms of the particular group of contributing parameters. A general schematic of the resulting model and the contributing parameters are illustrated in Figure 6-21.

The exposure and detection submodels correspond to the first sequential requirements listed, while the latter two requirements have been combined in the identification submodel. Each submodel addresses a specific question relative to the sequential requirements for successful acquisition.



QUESTION	QUESTION	QUESTION	QUESTION
Does line-of-sight exist to target?	Is Target presence visually detectable if viewed?	Is Target visually sampled and discriminated as "target" at range R?	What is the probability of exposure, detection, and identification at discrete ranges?
Navigation accuracy Target location error Field of view Altitude Terrain masking Proximity masking Vertical target extension	Illumination Target size Contact Atmospheric effects Color Projected shape Background brightness	Background complexity Contextual cues Pre-mission intelligence Speed Performance aids Geographic orientation Crew composition Repeated passes	

SOURCE: Gilmour, 1972

Figure 6-21. Structure of Boeing Target Acquisition Model

The form of the model is expressed as

$$P_A = f\ (P_E, P_D, P_I)$$

where

P_A is probability of acquisition of a target

P_E is probability of exposure

P_D is probability of detection

P_I is probability of identification

The exposure probability, P_E, is described as made up of a probability that the target falls within the search area, P_S, and a probability of being unmasked, P_m . P_S includes effects of navigation errors, target location errors, and effective search swath width.

The detection probability, P_D, is obtained using a single-glimpse detection lobe probability and a simplified search strategy, accumulated over the selected time interval. The detection lobe equation is empirical, based upon laboratory and visual simulator data connecting apparent contrast, luminance level, and the angle off the visual axis.

The identification probability, P_I, takes the form of a decrement in performance compared with the exposure and detectability criteria. Thus, range at identification is expressed as

$$R_I = R_{E,D} (1 - SR)$$

where

$R_{E,D}$ is the range at which the target is exposed and detectable.

SR is the search performance ratio, $\frac{X}{X + Y}$ where X is the distance from first availability range, and Y is distance from identification range to minimum available range.

The value of SR is considered to be predictable from measures of background complexity, target/background context, intelligence data, and search task dynamics. The method of measuring and combining these factors is not detailed in the basic report. See Zaitzeff (1971) for an experimental approach using analysis of films.

The concept of an acquisition probability compounded from probabilities of exposure, detection and identification is not unusual. The treatments of masking and detection are also similar to other models. However, identification is handled differently than other models. In most analytic models the recognition or identification of a target is presumed to depend mainly upon the ability to resolve critical details and probability is modeled primarily as a function of system resolution. The importance of resolution is not denied but the model approach suggests that there is sufficient commonality among targets and backgrounds of interest to permit the use of "search performance ratio" as a broader predictor of performance. The model thus assumes that, in situations of interest, the range at which a target is likely to be identified depends more heavily upon scene complexity, briefing data and target motion than it does upon visual resolution limitations. SR, however, becomes hard to predict when dealing with new locations or situations where little target data are available. Thus, the model's utility in tactical situations is dubious, even though it may be a useful tool for some equipment evaluations.

Formal validation of the Boeing Model has not been reported in the open literature.

6.3.10 Bailey-Rand Model

The Bailey-Rand Model (i.e., Rand Model) determines the probability of recognizing a target with either the naked eye or with an electro-optical sensor (Bailey, 1970). While published in 1970, "it was developed during the mid-1960's and was used internally at Rand prior to its publication" (Bailey, 1972). Bailey's concepts also provided the basis for the GRC model which in turn has been used by MARSAM II and several other less well known models (Greening, 1973). The modeling approach uses the product of separate independent conditional probabilities as follows:

$$P_R = P_1 \cdot P_2 \cdot P_3 \cdot \eta$$

where

P_R The conditional probability of "recognition," defined as the conscious decision that "there is the target,"

P_1 The conditional probability that one glimpse falls upon the target.

P_2 The conditional probability that, if viewed for one glimpse, the target will be detected.

P_3 The probability that, if detected, the target will be recognized by shape.

η Is the degradation arising from signal-to-noise on the electro-optical display that is viewed by an observer.

Figure 6-22 shows the general model structure. The values of conditional probabilities are determined as follows:

An assumption of random search of the target area is made, the search term is:

$$P_1 = 1 - \exp\left[\frac{-700}{G} \cdot \frac{a_T}{A_s} \cdot t\right]$$

where

G is a "congestion factor," normally near 10, but varying from 1 to 100. It can be viewed as the number of "fixation centers" in a "glimpse aperture,"

a_T is area of target

A_s is area to be searched

t is time available for search.

Derivation of the search term is based upon an assumption that the observer fixates fairly systematically with foveal vision. The number of glimpses that are available in a second of time are assumed to be 3,

or a fixation time of .33 second per glimpse. For a specific search area A_s, the probability of looking at a target is the ratio of A_s to the area of each glimpse A_g, at a rate of 3 glimpses per second. The congestion term is conceptually equivalent to clutter. The target area scene can have any number of objects which may have visual characteristics similar to the target. These become "natural" fixation points for the eye and will degrade, or reduce the purely systematic search assumption. The "clutter factor" or scene congestion is usually found to be some value from one to ten, based upon the estimates of experienced observers.

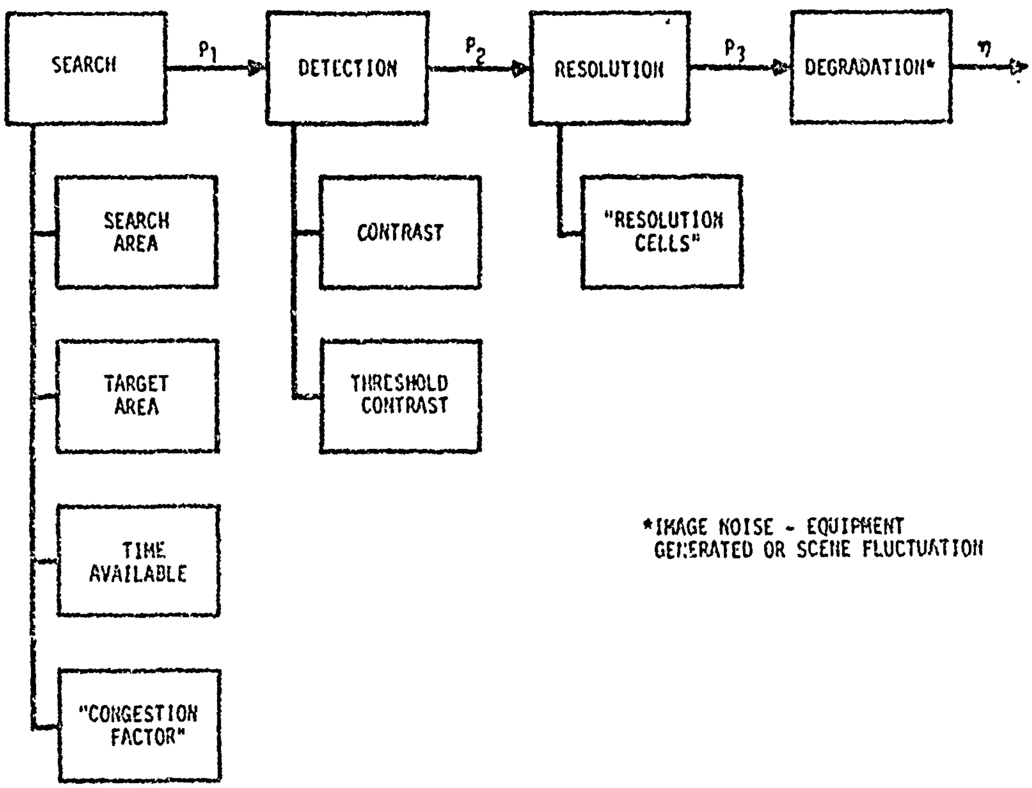


Figure 6-22. Bailey-Rand Model Structure

The detection term is primarily based upon the Blackwell and Taylor data for visual contrast detection in a homogeneous visual field.

$$P_2 = \frac{1}{2} \pm \frac{1}{2} \left\{ 1 - \exp \left[-4.2 \left(\frac{C}{CT} - 1 \right)^2 \right] \right\}^{1/2}$$

where

C is target/background contrast, at the eye.

C_T is threshold contrast, obtained from:

$$(\log_{10} C_T + 2)\ (\log_{10} \alpha + 0.5) = 1$$

where

α = target subtense in minutes of arc.

The expressions for P_2 and C_T are algebraic approximations to some of Blackwell and Taylor's data for .3 seconds visual glimpse. The C_T value is adjusted by a factor of about 5.5, as a "field factor" to account for the transition from simple laboratory to complex field situations.

The resolution term has to do with the subjective act of deciding what a particular image form represents in the real world (Bailey, 1970). This part of the model is deliberately conservative. It covers the case where shape provides the primary criterion for recognition.

$$P_3 = \begin{cases} 1 - \exp\left[-\left(\frac{N_r}{2} - 1\right)^2\right] & N_r \geq 2 \\ 0 & N_r < 2 \end{cases}$$

where

N_r is the number of "resolution cells" in the minimum dimension of the target.

Number of resolution cells is based upon the Johnson criteria concept (see Section 4.2.1); as N_r varies, so does P_3; thus $P_3 = 0.9$ when $N_r = 5$. Bailey clearly makes the point that N_r is based upon the real target values developed by Johnson and others and not typical bar chart resolution targets.

For the direct visual case the first three terms are used. When modeling the visual acquisition of targets using an E-O display, the effects of electrical noise must be included. Here,

$$\eta = \begin{cases} 1 - e^{-[S/N - 1]} & S/N \geq 1 \\ 0 & S/N < 1 \end{cases}$$

where S/N is the ratio of input signal to display noise. The quantity η is an overall degradation factor arising from any noise in the displayed image that is viewed by the observer. Bailey (1972) noted that this E-O term might not be as appropriate as a "perceived signal-to-noise" or any other type of visual noise term. The model structure allows this change with ease.

The sequential, probabilistic structure of the Bailey-Rand model is typical of recent models (Greening, 1973). The approach makes it practical to replace or modify submodels to fit a specific situation or sensor. For example, Mendez, Freitag, and Hallenback (1972) used a derivation of the Bailey model to help analyze and predict FLIR sensor performance. The effects of various elements in the acquisition process are fairly easy to segregate, and the model is amenable to hand calculations.

The Bailey model represents a compromise between the early essentially analytic-constructive modeling efforts of Lamar and Koopman and the operational data methodology approach of Franklin and Whittenburg. The Bailey submodels are each based upon both selected laboratory and field data. The model is essentially conservative. Extensive validation has not been reported; however, two sets of E-O data have been evaluated using the model. Mendez (1972) reported an analysis of MAFLIR test data. While the exact results are classified, in general the model effectively predicted field test performance of this E-O system. Jones has recently compared the results of several terrain model simulator target acquisition experiments using television (Fowler and Jones, 1972) with predictions of the same data based upon the Bailey-Rand model. While the model tended to under-predict the mean target acquisition ranges of 15 observers using a standard 525-line black and white TV, the model predicted the experimental data rather well. The product-moment correlation between predicted and averaged performance was +0.78 which is significant at the .001 level of confidence (D.B. Jones, personal communication, 1973).

6.3.11 Consideration of Mathematical Models

How good are the mathematical models? The answer to this question comes in two related parts. First, is the model valid; does it really evaluate the target acquisition process? Second, is the model practical; can it be used effectively to evaluate target acquisition; and are the results useful as a design tool, or as an operational guide?

The specific evidence or absence of validity has been noted for each of the models. Validation of such complex models as those for target acquisition is very difficult. To validate a model, predicted performance is correlated with measured performance over the range of concern. The measured performance must also be stable and reliable. Unfortunately the results of target acquisition field tests are not very stable or reliable. Human performance tends to be variable in even well controlled conditions. A reasonably large number of trials are required to establish firm data points and the dispersion about those values. The costs of field testing make extensive flight trials nearly prohibitive. As a result most flight test data are not definitive. Finally, many of the variables such as illumination, atmosphere, target background, clutter, masking, etc., are nearly impossible to measure or control in the field. Greening (1973) notes that there are four possible ways to establish target acquisition model validity:

1. Use a full-scale field test with a number of observers, several aircraft, realistic ground targets placed in realistic settings, and a complex of instrumentation and measuring equipment. The results can then be used to validate (or invalidate) a model. Examples are VISTRAC

(JTF-2), Erickson and Gordon (1970), Franklin and Whittenburg (1965).

2. Validate in controlled, less expensive simulation. (This approach implies a second problem, that of establishing the validity of the simulation.) Examples are VISTRAC (JTF-2), Boeing and Autonetics models.

3. Construct the model from submodels of laboratory established validity, combined in ways which yield predictable results. Validity is thus partly established in advance. The skill and insight used in selecting submodels are important. Valid submodels for all relevant parts of the acquisition process are not now available. The Bailey-Rand and the GRC models are examples.

4. Construct a simple, generalized model which includes several adjusting constants, and evaluate the constants either from existing field/simulator data, or from field trials set up for this purpose, i.e., the Autonetics model.

In practice, none of these approaches has been used exculsively. A modeler should attempt to construct his model from valid submodels where he can, should seek other validation data wherever they can be found, and should adjust the model when possible. The basic approaches to validation have had different emphases in the selected models.

The MARSAM II model, the GRC/A model and the Bailey's model are modular models constructed from simpler elements. The submodels were presumed valid because each was based upon field or laboratory data. If the submodels can be presumed to be a complete set, to be combined properly, and to be representative of the steps in the target acquisition process, the total model would be valid. For some of the terms of submodels this is true. However, there is difficulty with respect to search. A good, clearcut search submodel, based upon data, was not to be found. So GRC/A MARSAM II and Bailey each have different, unvalidated search elements. There is also no evidence as to how the submodels should be combined. Are they really sequential combined probabilities, or additive, or some other combination?

The Autonetics and VISTRAC models are basically simple exponential representations of the increasing probability of acquiring a target as an observer flies toward it. The VISTRAC model is based on the Lamar visual lobe equations. Three constants were included, to match either field or motion picture simulator data. Validation using the JTF-2 data was tried; however, the highly variable field results do not allow any real comparison.

(See Figures 6-12 and 6-13 for examples.) The Autonetics model has been validated against motion picture simulations using fairly large targets with good results (Greening and Wyman, 1970).

The SRI CRESS/SCREEN models are based on the Franklin and Whittenburg model which, in turn, was developed by fitting an analytic expression to field data. Thus, the Franklin and Whittenburg model was at least valid for the range of test conditions which were used to establish the values. The validity of CRESS/SCREEN target acquisition can be assumed to be established to the extent that it conforms to the Franklin and Whittenburg formulation and is limited to Whittenburg's field conditions. But the contrast term is expressed rather differently leaving the validity open to some question, even for the rather narrow range of conditions covered by the earlier model. In general, however, none of the models has been adequately validated in a broad range of conditions and using several methods of validation.

In spite of the diversity of target acquisition model development, there is a strong resemblance among the models. The pattern is indicated in Figures 6-3 and 6-4. The "detection lobe" approach has been dominant. This has resulted in a great deal of effort being devoted to the definition of liminal performance boundaries for detection and for resolution of detail. The off-axis vision is typically handled in the lobe models by assuming a "cookie cutter" lobe. One full scale field test included detection lobe model validation with poor results (Erickson and Gordon, 1970).

Most of the models have ignored the observer's functions. The Franklin and Whittenburg approach was initially purely field-data-descriptive. No reference to visual performance data from the laboratory was made. Instead, more subjective characteristics, such as conspicuity, were determined by the judgement of expert observers. These values were then combined algebraically to fit field data. The Boeing approach resembles this in some ways, although with less reliance on judged quantities. Recent work in Great Britain has also included a subjective human factors element, as well as continued effort on refined visual lobe descriptions.

When the models' contents and consideration of variables are compared with the number of factors affecting target acquisition as shown in Figure 6-1, it is obvious that most models have considered only a few target elements, the geometry involved (it is easy to model), and part of the environmental factors. Less effort has been expended on the ability to resolve detail in target images, the distribution of search over the field-of-view, and the effects of non-target objects, and noise in the display. The widely different search submodels and the lack of validation indicate the need for more work here.

The operators' functioning is omitted entirely in most or all of the models. The influence of the perceptual set and associated decision criteria are not mentioned. (What constitutes the decision to say, "That is a target"?) How are training, experience, stress, fatigue, and task loading considered?

In spite of doubtful model validity the results are useful as long as the user recognizes the limitations involved. The currently available target acquisition models do indicate trends and limiting effects. They can be used to establish bounds in equipment design or to compare possible system approaches for helping solve the target acquisition problem. Operationally the models can also be used to set limits and conduct parametric studies of performance.

6.3.11.1 Summary

Which model to use? That depends upon the purpose for which it is to be used, the conditions which are of concern in the evaluation and the degree of validity acceptable. The user may even desire to change a model or try to develop a new one to better meet his own needs. Any decision to use a model is in part subjective. However, based upon the conditions for which the model was originally designed as well as the types of validation reported it is possible to decide which model best fits those conditions. Table 6-I thus is a suggested use for nine of the models reviewed.[1]

When it is necessary to evaluate system performance in detail, or to make key design decisions, then some other evaluation means is needed - usually simulation or field test.

6.4 Visual Simulators

Obtaining valid performance data under operational conditions is both difficult and costly. Thus, simulation plays a vital part in evaluating target acquisition. Simulation is defined as the representation of an actual physical object, process or situation, or of a theoretical construct.

[1] Computation requirements and electronics data processing (EDP) capabilities may also be a concern. The factors in EDP use are beyond the scope of this sourcebook; for a discussion of EDP requirements and capabilities see Greening, 1973. In general the Franklin and Whittenburg and Bailey models are amenable to hand calculation. All the others require varying degrees of EDP capability. MARSAM II is particularly well documented and the EDP programming clearly defined. This may account for much of its obvious popularity.

TABLE 6-I

OPERATIONAL CONDITIONS EFFECTIVELY CONSIDERED IN TY

TYPICAL MODELS	TARGET TYPE			TARGET CONDITIONS					
				DENSITY		BACKGROUND			SI
	SMALL (INFANTRY WEAPONS)	MEDIUM (TRUCKS, TANKS)	LARGE (AIRFIELD, BUILDINGS)	FEW	MANY	CLUTTER	MASKING	TERRAIN	<20(
CAL-RYLL	X	X		X			X	X	X
GRC A	X	X		X		X			
HARSAM II		X	X		X	X	X		
VISTRAC			X	X			X		
Autonetics			X	X			X		
Franklin & Whittenburg	X	X		X			X	X	)
CRESS/SCREEN	X	X			X		X	X	X
Boeing			X	X			X	X	
Bailey	X	X		X		X		X	

.E 6-1

ISIDERED IN TYPICAL ACQUISITION MODELS

	AIRCRAFT TYPE					SENSOR			OBSERVER
	SPEED		ALTITUDE (FEET)						
	SLOW	FAST	LOW	MEDIUM	HIGH	EYEBALL	E-O	SEARCH	AXIS OF VIEW
TERRAIN	<200 KTS	>200 KTS	<1500	<10,000	>10,000				
X	X		X			X		Systematic	±45° Off Center Axis
		X	X	X		X	X	Random	Fixed FOV
		X		X	X	X	X	Systematic	Fixed 5° Forward
		X	X			X		Systematic	Fixed Forward
		X	X	X		X		Fixed	Fixed Forward
X	X		X			X		Systematic	±45° Off Center Axis
	X		X			X	X	Systematic	±45° Off Center Axis
X		X	X	X		X	X	Systematic	Forward
X		X		X	X	X	X	Random	Forward

The representation is either physical or symbolic, or some combination of the two. Physical models usually are similar to the objects they are intended to represent. The extent of resemblance varies however. In some the simulator is virtually identical in physical appearance while in others it is only typical. Symbolic simulators can reproduce the processes of the real-world system, but there may be little or no apparent resemblance in physical characteristics. For instance, the mathematical models noted in the previous section represented symbolically by mathematical equations the target acquisition process. This section however, is concerned with visual simulators as used in testing and evaluation of target acquisition. Hereafter, the term "simulation" will refer to visual, physical representation of the real-world.

A well planned simulation program can develop design and performance data under controlled conditions at relatively low cost compared with the costs of field tests. A well designed simulation can often approximate the controls of the psychophysical laboratory while also approximating realistic human performance tasks. An effective simulation must be sensitive to significant input parameters and also provide appropriate responses in terms of outputs. Finally, the outputs must be translatable into real-world measures of performance. The degree to which a simulator can accomplish these things is a measure of its actual fidelity.

This section will consider the simulation methods that have been used to evaluate target acquisition. (A thorough review of visual simulation techniques, not limited to target acquisition, can be found in the report by Bliss, 1969.)

Obtaining reliable target acquisition data under conditions which incorporate the dynamic and visual characteristics of the real-world is complex. A qualitative three-dimensional diagram as shown in Figure 6-23 (adapted from Greening, 1964) illustrates the problem. Two axes of the diagram represent the fidelity of the situation in terms of the visual and dynamic complexity of the environment, and the third axis represents the degree of experimental control. Visual complexity refers to the appearance of the terrain as seen from the air. Dynamic complexity refers to the changing appearance of the terrain due to the movement of the aircraft over it. The third axis represents the extent to which the factors under investigation can be systematically varied, while other significant factors are maintained constant.

Target acquisition simulation is aiming at the far top right-hand corner of this diagram-realistic visual and dynamic complexity combined with a high degree of experimental control. This is often impossible, but the different techniques used in target acquisition research approach the ideal situation in different ways. Flight tests achieve maximum visual and dynamic realism but have relatively little experimental control. High-fidelity simulation techniques are less realistic in terms of the visual and dynamic characteristics of the outside world but can provide better experimental control.

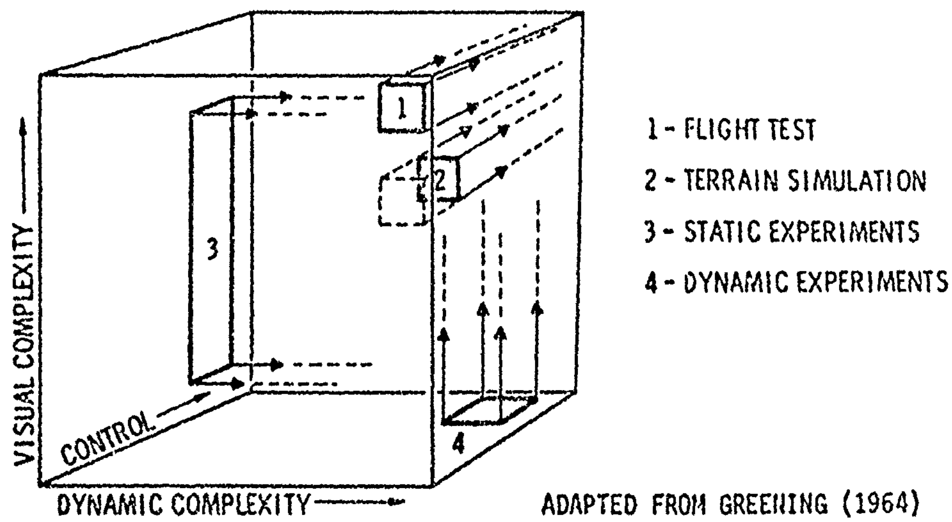


Figure 6-23. Schematic Representation of Target Acquisition Research

6.4.1 Techniques of Visual Simulation for Target Acquisition

Target acquisition is traditionally carried out by direct observation of the terrain from the aircraft. For simulation of these tasks the main requirement is a visual display which accurately reproduces the appearance of the terrain as seen from the cockpit during flight. Alternatively, target acquisition can be carried out by means of an electro-optical (usually television) sensor system that relays to the aircraft a view of the terrain. For this task the required simulation is the E-O sensor's view of the terrain. The display requirements for the two types of simulation differ in certain important respects. Direct view requires a relatively wide-angle, usually full-color and high-quality display outside the cockpit. Simulation of television or other E-O viewing requires a small in-cockpit display of a relatively narrow field of view, and of quality comparable to live TV. The different requirements have significant implications in terms of simulation techniques to be used.

Two fundamentally different techniques are in common use for high-fidelity terrain simulation. The first uses motion picture imagery obtained by filming the real-world from an aircraft. The second uses a terrain model to provide an appropriate view of the terrain to the cockpit. The terrain model is also often used for TV simulation. Each technique has advantages and disadvantages. The choice between them depends on the nature of research to be carried out, and the amount of time and resources available.

6.4.2 Motion Picture Simulation

Motion picture simulation is used by many researchers in evaluating direct-view target acquisition performance. (See, for instance Gilmour, 1964, Gilmour et al., 1968; McGrath and Borden, 1964; Snyder and Calhoun, 1965, and Self, 1971.) Films are relatively easy to acquire and to use and provide obvious face validity; that is, the picture certainly appears like the real world.

The main advantage in using a motion picture is that it enables not only major terrain features, such as woodland, towns, lakes, railways, and mountains, to be accurately simulated but also much more subtle effects such as textures, contrast, illumination and shadows, masking clouds and seasonal changes. Film simulation facilities usually are less complex and expensive to set up than terrain-model systems. In particular, film simulation does not necessarily involve the use of computer facilities, and usually requires less space than terrain-model simulation. Since the film is, in effect, a visual record of the appearance of the terrain during an actual flight, visual and dynamic realism are ensured, providing that adequate color and image resolution can be achieved.

For maximum realism the field of view should be comparable to that actually seen from the operational aircraft. Field-of-view requirements for effective simulation have not been established. The JTF-2 motion picture simulator provides a relatively high resolution 160 degree horizontal and 60 degree vertical color film display. Many motion picture target acquisition simulation studies have been conducted, however, using smaller fields of view, typical of standard commercial 16 millimeter motion pictures.

The outstanding disadvantage of motion picture simulation is that it is completely pre-programmed. Context, vehicle speeds, altitudes and attitudes are all fixed in the film and cannot be influenced by the operator without the destruction of correctness of perspective. (Speed can often be varied over a restricted range by changing the projection speed.) Not only can the parameters of the simulation not be changed by the operator during a run, but the parameters cannot be changed from run to run unless duplicate films with different parameters have been obtained. Film is also fragile and expensive if multiple prints are made in order to avoid the loss of runs through film wear. The use of multiple prints also produces degradation in film quality. Since the pilot cannot control altitude or track and can only make limited adjustment, if any, to speed, he observes rather than flies. Thus, only partial simulation of the pilot's task can be achieved. The simulation is usually of the task of an observer, not a pilot. Finally, the target scene is not subject to control. The conditions are real and not as precise as may be desired.

Motion picture simulation allows very accurate measurements of acquisition range since the film frame count can be recorded at the moment the subject makes a response. Frame count can easily be converted into a range value from knowledge of the distance moved by the aircraft per

frame and the total length of the run. Thus, measurement of response data is usually relatively easy to do.

The limitations of using motion picture for simulation were partially overcome in the three JTF-2 simulators built in the 1960's (Snyder, et al, 1966). The motion picture used 70 mm color film over a field of view of 160 degrees by 60 degrees. Figure 6-24 is a view of one of these visual simulators. It can be used to simulate either visual or instrument flight. The cockpit is fully activated and equipped for a number of different types of studies including target acquisition, the evaluation of sensor displays, terrain-following and ground attack. For target acquisition studies the flight path of the simulator is determined by an autonavigation system in conjunction with pre-set check-points along the test course. In the instrument flight mode the pilot can control his own flight path within a 25-mile wide corridor. The simulator is computer-driven and represents perhaps the most sophisticated application of motion picture film simulation techniques currently in operation.

6.4.2.1. Motion Picture Simulation Validation Studies

Although many of the target acquisition studies listed in this source book have used motion picture simulation, only a very limited number have been validated by comparison with field test data.

Snyder and Calhoun (1965) compared recognition ranges determined in the laboratory from motion picture film simulation with those for the same targets determined during JTF-2 flight trials (all targets were large - highway overpass, lake, buildings, etc.). In this case very large discrepancies between field and simulator results were found. In the flight trials, individual targets were recognized at ranges varying from twice as great to almost twelve times as great as in the simulation trials. It seems likely that inadequate experimental control and/or different response criteria under the two conditions may have contributed to the results. (The field tests did not have as much control as was possible in the laboratory.) An analysis of these results is shown in Table 6-II.

The most extensive comparison between field and motion picture simulator data was that carried out to validate the multi-mission motion picture simulator developed for use in the JTF-2 program. The main purpose of this study, which has been reported by Gilmour, et al (1968), was to evaluate the extent to which the simulator could be used as a valid means of predicting the effects of certain important target acquisition variables under field conditions. Additional objectives were to investigate the effects of speed and altitude under simulation conditions, and to derive functional performance relationships useful in a mathematical model of visual target acquisition.

The JTF-2 simulator provided a fairly realistic representation of the test routes used in the field trials. In the simulator study, three speeds, 190, 360, and 550 knots, and three altitudes, 61, 122, and 183

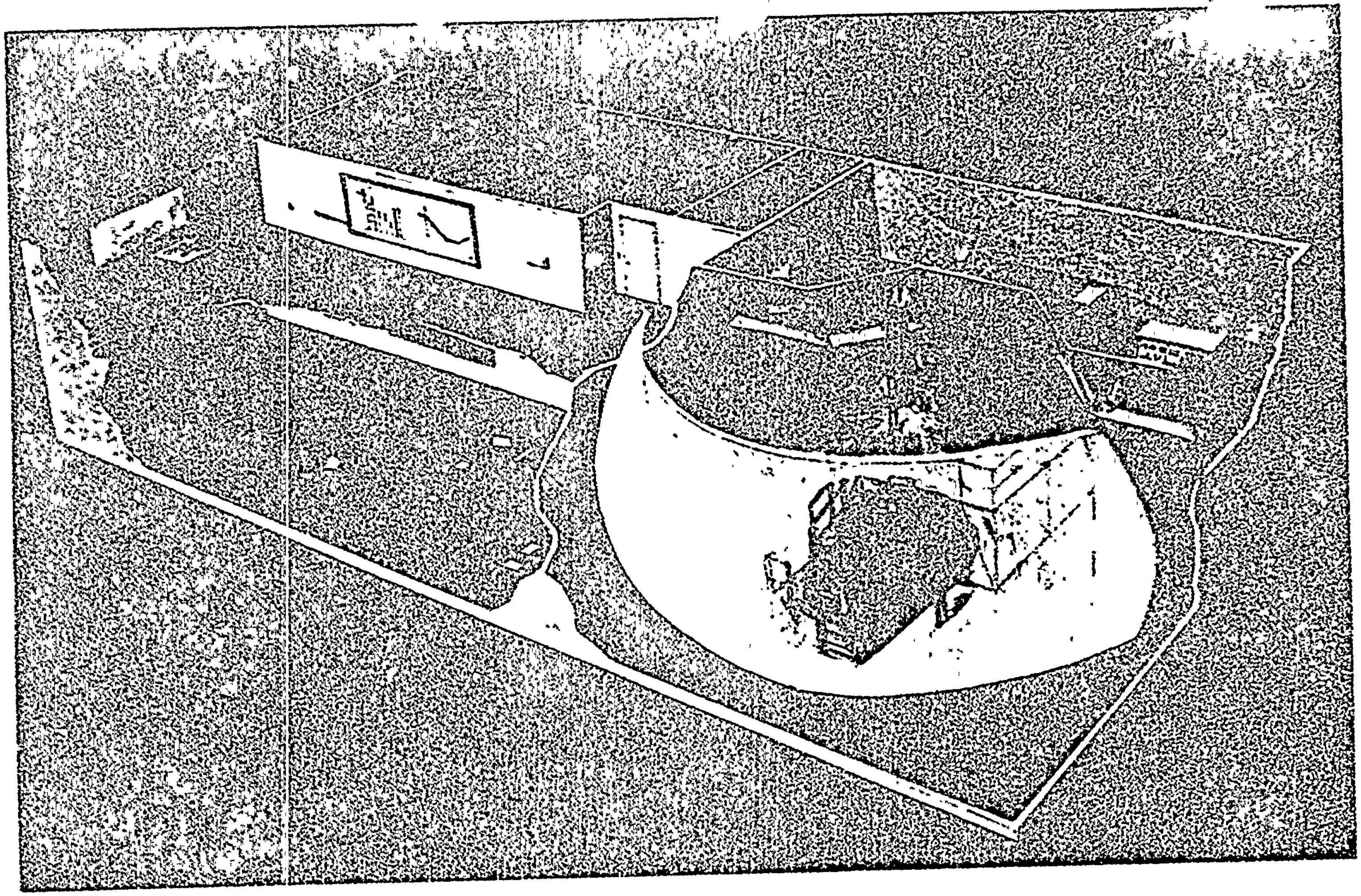


Figure 6-24. Boeing Multimission Simulator Facility

meters were tested, together with the supersonic speed of 764 knots at an altitude of 122 meters, giving a total of ten conditions. Sixteen military pilots were assigned to each of these conditions and all mission briefings exactly duplicated the relevant parts of the field test briefings.

TABLE 6-II

Median airborne target acquisition ranges (across four flights) and mean laboratory ranges for the 14 targets

Target	Mean Laboratory Range		Median Airborne Range	
	(ft)	(meters)	(ft)	(meters)
1	6,256	1,907	37,136	11,319
2	6,093	1,857	32,736	9,978
4	3,933	1,199	34,496	10,514
5	5,068	1,545	23,584	7,188
6	2,583	787	16,192	4,935
7	3,825	1,166	7,392	2,253
8	7,282	2,220	22,880	6,974
9	7,066	2,154	18,480	5,633
10	9,659	2,944	39,072	11,909
11	4,365	1,330	51,744	15,772
12	6,310	1,923	45,936	14,001
13	8,309	2,533	98,060	29,889
14	7,390	2,252	29,216	8,905
15	5,662	1,726	27,104	8,262
	$\overline{X}$ = 5,986	1,825	$\overline{X}$ = 34,573	10,538

Source: Synder and Calhoun, 1965.

The comparison of field and simulator data was based on the performance measures (range and probability of acquisition) obtained for the eight targets, four along each of two test routes, common to both trials. Functional performance relationships derived from the field test and simulator data were compared to evaluate the capability of the simulation technique to predict speed, altitude, and target effects found in the field tests. The main points derived from this comparison were as follows:

1. In terms of acquisition probability for individual targets, a product-moment correlation of +0.86 between the field and simulator data was obtained. The simulator data were able to predict about 76 percent of the field test variability in acquisition probability. Corresponding values for acquisition range were +0.78 and 61 percent.

2. Acquisition ranges as determined from the motion picture simulation were consistently lower, in absolute values, than those obtained under direct view field test conditions. This disparity increased as acquisition range increased. This result suggests that measured acquisition ranges with motion picture simulation would tend to underestimate the performance improvement likely to occur under field conditions. (The same result was reported by Snyder and Calhoun.)

In general, the results of these studies indicate that motion picture simulation is a valid means of obtaining empirical target acquisition data for the systematic evaluation of speed, altitude, and target effects. Although the technique does not exactly duplicate in-flight direct viewing conditions (there were differences in absolute performance levels), when viewing differences and possibly projector system resolution were considered, the two methods (motion picture simulation and field tests) were in close agreement on the effects of critical variables. The trends are in the same direction even though absolute values were different.

6.4.3 Terrain Model Simulation

Motion picture film must copy what is in the target scene. The terrain model, on the other hand, allows more precise physical control of the target area and may offer more freedom for the observer. Probably the oldest method of simulating the visual field is the direct viewing of a terrain model. It was used during World War II by the Army Air Force, and more recently, by Blackwell, et al, in target acquisition studies.

The limitations of the terrain model are primarily mechanical. To simulate a large visual area requires a large model. Thus, it is awkward and difficult to make scene changes. Many atmospheric conditions are difficult or impossible to realistically simulate. (However, this may be an advantage since the problems of atmospheric degradation or distortion are not present.)

In some cases visual simulation is achieved by the observer viewing the terrain model directly. In others, a televised (or other E-O sensor) view of the terrain model is relayed to the simulated cockpit. When used with E-O sensors, the operator can easily be "coupled" with the scene without loss of signal. The TV technique provides a visual representation of the outside world in the simulation of flight. The cockpit controls are linked through analog computers to a television camera moving over a three-dimensional terrain model. Each control input made by the pilot not only activates the cockpit instruments, but also the TV camera and link transmit the visual display back to the pilot.

If the E-O sensor is mounted on a system allowing full movement in six degrees of freedom, a visual display corresponding to any maneuver made by the pilot can be obtained. On some terrain tables, one degree of translational movement is provided by movement of the terrain model itself with respect to the sensor head. Appropriate motion cues, synchronized with the pilot's control movements, can also be simulated by the use of a moving base cockpit (this adds to the expense of the system). The fidelity of E-O imagery obtained by means of terrain model simulation is limited by a number of factors, the most important of which, are the resolution of the sensor, the field of view, the apparent distance of the terrain scene, and the scale of the terrain model.

Terrain models have been used for both direct view and E-O sensor studies of target acquisition (Blackwell, et al, 1959; Schohan, et al, 1965; Fowler and Jones, 1972; Bruns, et al, 1972).

Terrain model simulation has several distinct advantages. The perspective is correct in a terrain model and the dynamics of perspective change with translation of the observer over the terrain model are correct. Runs across a terrain model can be unprogrammed to a considerable extent, although the extent of flexibility in runs is limited by the terrain model size and the size of the field of view of the observer. There is great flexibility in control of the stimulus in a terrain model. The content can be whatever is required, and inherent contrast, colors, degree of complexity, absolute size, and the scale of the model can be varied almost without limit. Great control over illumination and considerable control over visibility conditions can be maintained, and any of these characteristics can be changed as necessitated by the particular simulation problem. Properly designed, set up, and used, the terrain model can provide a degree of stimulus control that is almost equal to that of the psychophysical laboratory.

Using a model to provide the source of terrain imagery, rather than the real world, allows much greater experimental control to be exerted over the nature of the terrain studied in terms of clutter, contrast, and position of conspicuous terrain features. Similar control can be exerted over the nature and position of targets. In particular, the use of a suitably designed terrain model, which allows normally fixed targets such as bridges or buildings to be moved from one position to another, enables target and background effects to be evaluated independently

whereas this is not possible by any other technique. Alternatively, the model can be designed to exactly duplicate a particular area of terrain so that performance under simulator and real world conditions can be directly compared.

The disadvantages, however, are also significant. The most important disadvantage in considering the use of the terrain model with a sensor system is the restricted display size that is available with current display systems. The second disadvantage of a terrain model-television system combination is the degradation which is imposed on the image by the optical and electronic components of the system: resolution, both horizontal and vertical; different spectral response in the television system as compared to the eye which affects both gray scale contrast and color rendition; the "smear" which occurs with movement of the television camera across the terrain model surface; and the limited field of view imposed on the system by lens size. The final two disadvantages of this simulation system are the physical size required by a terrain model and the expense associated with the development, maintenance, and use of a large terrain model system. Even small terrain models can be expensive to set up if precise control of lighting and target area is maintained.

Scale size affects the degree of realism that can be obtained from a terrain model. The smaller the scale the greater is the area of terrain that can be simulated in a given space. However, larger scales achieve more realistic representation of detail, which is of great importance in target acquisition tasks. For instance, at a scale of 3000:1, a vehicle 30 meters long in the real world would measure only one centimeter, which obviously does not allow scope for any detailed modeling. For this reason, scales smaller than 2000:1 are not usually satisfactory for target acquisition studies, and scales such as 1200:1, 600:1, or even 200:1, depending on the size of the targets to be studied, are preferable. Combined models of two different scales are sometimes used; for example, 3000:1 for the navigation part of the task and 600:1 for the target acquisition task.

The simulation facility of the Columbus, Ohio plant of Rockwell International Corporation is typical of a closed loop combined terrain model simulation for E-O sensors. This equipment includes:

1. A six degree of freedom sensor transport which moves over a 3000:1 scale terrain model. A section of the model duplicates real terrain near the area, thus, allowing comparisons to be made between simulated and real-world conditions.

2. A variety of interchangeable terrains up to 3.66 X 11 meters in size with scales ranging from 1200:1 to 400:1, together with associated sensor transport systems.

3 A four degree of freedom motion base cockpit with associated controls and displays. A large rear projection screen is mounted in front of the cockpit and movement of the projected display synchronized to that of the cockpit.

4 Television monitor displays, projection facilities, and an analog/digital computing capability.

These facilities have been used for studies of missile guidance, remotely piloted vehicles and research in television target acquisition. The equipment is also suitable for studies of terrain-following, the evaluation of heads-up displays, the effect of task loading and fatigue, and related work. It does not allow dynamic simulation for direct view target acquisition studies. Representative studies include Schohan, et al (1965); Soliday and Schohan (1965); Soliday and Milligan (1968); and McGehee, Roscoe and Thill (1972).

A different type of sophisticated terrain-model simulation is available at the Martin Marietta Corporation, Orlando, Florida. A particular feature of this simulator is ability for the observer to view the terrain model directly as well as by a television viewing system. When used indoors, the model is illuminated by precisely controlled artificial lighting, either indirect or with a sun simulator. It can also be moved outside the building so that studies can be carried out under natural lighting conditions. The model measures 12.2 X 12.2 meters, at a scale of 600:1, which allows very realistic modeling; variable scales of 1200:1 to 200:1 are also used. The simulated terrain includes a wide variety of topographic features such as mountains, rivers, lakes, built-up areas, desert and farm land. The model is painted to simulate the "washed-out" color effect as seen from about 650 meters altitude, thus simulating some degree of atmospheric effect. The capability for a moving target (tank or truck) across the model surface is provided.

In this system, the sensor head (or the observation platform when the direct view mode is used) is mounted on a beam which moves vertically and laterally with respect to the terrain model. The third degree of translational motion is provided by longitudinal movement of the model towards the beam, (the model "flies" under the observer) while the gimbaled sensor head is capable of three degrees of rotational movement. Motion in all six degrees of freedom may be pre-programmed, or controlled from the simulated cockpit giving closed loop simulation. The moving model and solid beam arrangement provides an effective way of eliminating sensor "jitter" due to motion. Flight speeds from helicopter to supersonic aircraft can be simulated. When used with TV sensors, an aircraft cockpit is also provided. A television projector provides a view of the terrain model and allows the pilot to "fly" over the model.

A variety of acquisition studies has been conducted at the Martin Marietta facility as seen in Table 6-III. The facility (Guidance Development Center) is shown in Figure 6-25. A duplicate of this facility has recently been completed for the U.S. Army Missile Command at Huntsville, Alabama.

The two terrain models cited (Rockwell International and Martin Marietta) are only typical. Large, complex simulators need not be the only ones used. Excellent terrain models and examples of related target acquisition studies have been reported by the Human Factors Laboratory, Naval Missile Center, Point Mugu, California (Bruns, Whery and Bittner, 1970); the Naval Weapons Center, China Lake, California (Craig, 1971); McDonnell-Douglas Corporation in St. Louis (Levine, 1970); and U.S. Air Force Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio (Freitag, Hilgendorf and Searle, 1974). In addition to these smaller target acquisition terrain model simulators, a number of terrain model flight simulators, primarily designed for aircraft flight, and take-off and landing, are in use. The scale and terrain on most flight simulators are inappropriate for target acquisition studies.

An alternative to a rigid terrain model is the use of a flexible terrain belt mounted on rollers. Translational motion along one axis is provided by movement of the belt, the remaining five degrees of freedom being provided by movement of the sensor head. Terrain belts have the advantage of requiring less space than terrain models and, since they are continuous, they allow greater freedom of navigation than a corresponding area of rigid model.

Terrain belts are limited, however, in scale and operation. One disadvantage of terrain belts, as compared with rigid models, is the difficulty of achieving adequate three-dimensional modeling of mountainous terrain since the belt must remain flexible enough to move easily over the rollers. A further drawback is the tendency of the belts to deteriorate, particularly by cracking. The scale size must be such that terrain and other physical objects are not affected as the belt turns over the rollers, particularly in the vertical position. Because of this, scale sizes must remain in the 10,000:1 to 1,000:1 range. Belts may also tend to "flap" and thus cause distortion to the sensor. The Rockwell International Corporation in Los Angeles, California, for example, has a 1250:1 moving belt simulator.

6.4.3.1 Terrain Model Validation Studies

The most frequently cited experiment in which terrain model simulator data have been compared with flight trial data is that carried out by Blackwell, Ohmart and Harcum (1958). It is also notable because it was the first study of its kind. For the simulator trials, a terrain model was constructed which accurately reproduced, at a scale of 600:1,

TABLE 6-III

Summary of Target Acquisition Studies

Study Emphasis	Program Phases: I — TV Search, Detection & Recognition		II — Visual Search, Detection & Recognition	II — Visual Detection & Recognition Thresholds		III — TV Detection & Recognition Thresholds		IV — 2-D vs 3-D Targets		IV — TV Gamma Effects	V — Visual-to-TV Transition		V — Color vs Monochrome TV	
Test Identification	1a	1b	1	2a,b	2c,d	1a,b	1c,d	1a	1b	2	1a	1b	2a	2b
Operator Tasks & Independent Variables														
• Viewing Mode														
(1) Direct Visual			X	X	X			X			X			
(2) Monochrome (B&W) TV	X	X				X	X		X	X		X	X(6)	
(3) Color TV														X
• Scene Dynamics (Range Closure)														
(1) Continuous Convergence	X	X	X	X		X		X	X	X	X	X	X	X
(2) Static (Step) Convergence					X		X							
• Operator Tasks														
(1) Target Search	X	X	X								X	X		
(2) Target Detection	X	X	X	X(3)	X(3)	X(3)	X(3)	X	X	X	X	X	X	X
(3) Target Recognition	X	X	X	X(3)	X(3)	X(3)	X(3)	X	X	X	X	X	X	X
• Target Dimensionality and Type														
(1) 2-D Buildings	X	X	X	X	X		X			X	X	X	X	X
(2) 3-D Buildings & Vehicles								X	X					
• Target Briefing (within prebriefed area)														
(1) Unbriefed location within viewed area	X			X	X	X	X	X	X	X		X	X	X
(2) Unbriefed location within viewed area		X	X								X			
• TV Field-of-View (FOV)														
(1) Selected, fixed values for a given run	X	X				X	X					X	X	X
(2) Zoom(1)									X	X				
• Aim Point (TV)														
(1) Target offset from optical axis	X	X										X		
(2) Target on-axis (in central region of FOV)						X	X		X	X			X	X
• Target Area Background														
(1) Open	X	X	X	X	X	X	X		X	X	X	X	X	X
(2) Cluttered						X	X							
• Target/Background Discrimination Cues(2)														
(1) Brightness Contrast	X	X	X	X	X	X	X		X	X(4)	X	X	X	X
(2) Color Contrast											X			X

Legend: X and XX denotes primary inter- and intra-test variables

NOTES:
(1) Zoom lens programmed to simulate fixed FOV physical closure on targets at desired rates
(2) Primary cues in addition to size and form factor cues.
(3) Detection and recognition tests were performed on separate runs.
(4) TV displayed grey scale (and contrast) was varied by selecting different values of system gamma.
(5) Briefed by virtue of having prior direct visual location of the target.
(6) Color TV System used with chrominance channel switched off to produce monochrome display.

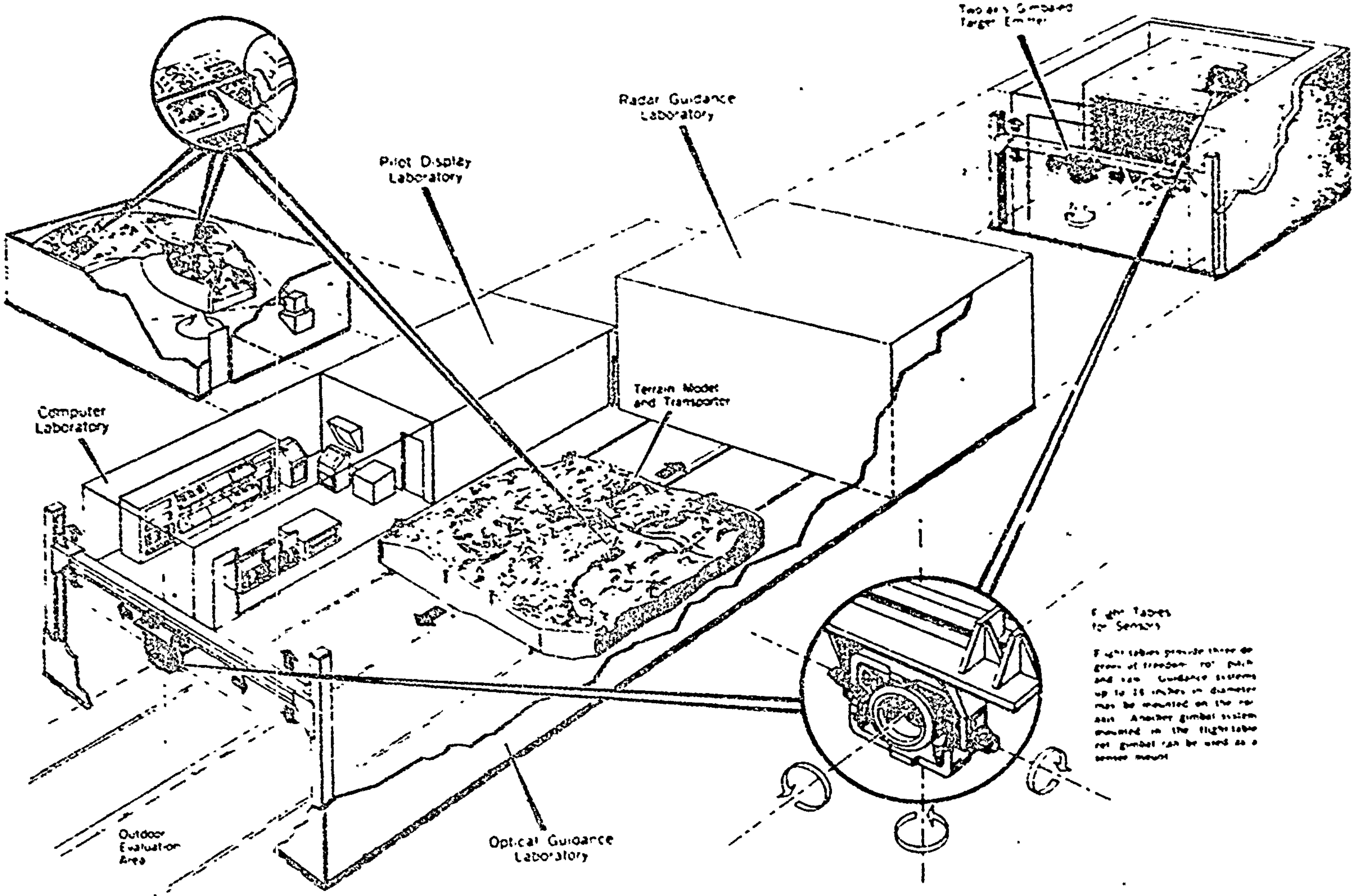


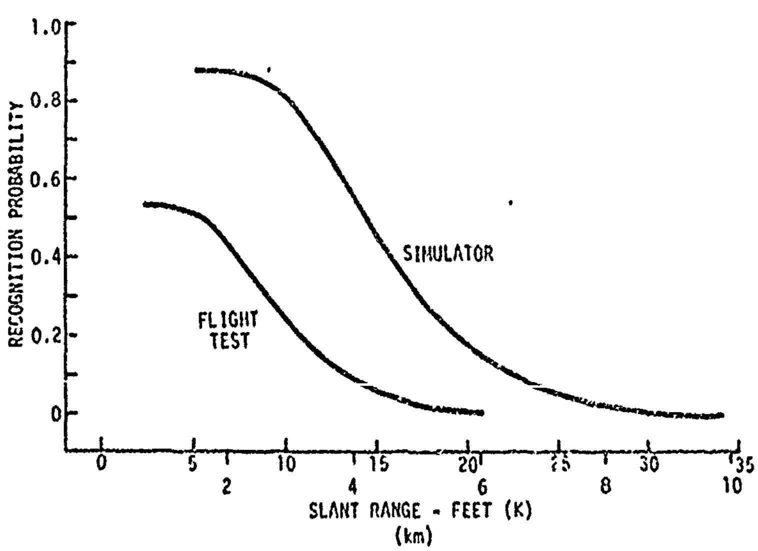
Figure 6-25. Schematic Layout of the Martin Marietta Terrain Model Simulator as Used for Target Acquisition Studies

the topography and detail of the ground area, approximately 2 kilometers square, chosen for the flight trial. The target, a line of three vehicles, could be positioned where required on the terrain model in such a way that the line was either parallel or perpendicular to the simulated flight path.

The remaining equipment consisted of a 5000 watt incandescent lamp which could be positioned as required to simulate the sun, and an observation platform (seat) which could be mounted at several heights, simulating different altitudes, on a dolly which traveled along a track. Four altitudes (610, 1220, 1740, and 2290 meters) were tested; recognition probabilities and slant ranges were obtained for several different sun positions. In all, 840 passes were made by the nine Navy reserve pilots who took part in the simulator experiment.

Flight trials were conducted against real targets located in the 2 km square area which was reproduced by the terrain model. As in the simulator experiments, the target could be located in any one of ten different positions within this area and the same nine pilots took part in the experiment. In these trials, a total of 109 flight passes were made.

Comparisons between the field data and the simulator data showed large differences although the trends were the same. For instance, at the shortest slant range, the recognition probability from the simulator experiment was 0.89, whereas under field conditions, it was 0.60. In each case, the simulator data were about 30 to 40 percent better than the field test data. Figure 6-26 shows the general results for all trials.



SOURCE: BLACKWELL, OHMART AND HARCUM (1958)

Figure 6-26. Effects of Altitude on Target Recognition

Blackwell, Ohmart and Harcum suggest a number of possible reasons for the lower performance under field conditions, including (1) the additional work load resulting from routine piloting tasks of the Beech aircraft, (2) vibration and turbulence of the aircraft, and (3) the optical imperfections and distortions of the windscreen. The pilots themselves commented particularly on the cockpit configuration which made forward viewing impractical and thus field observations had to be made from the side to a point nearly forward. Ohmart (personal communication, 1974) also believes that the operational situation had some stress effects since an Air Force fighter exercise was being conducted in the flight area and caused the pilots to be distracted. This, perhaps, also reduced performance in acquisition.

This study has been reviewed at some length as it illustrates some of the problems in validating simulation experiments by field trials. In addition, it is one of very few studies in which any attempt has been made to compare simulator and field data under reasonably well controlled experimental conditions. The 30 percent reduction in simulator performance to account for the impact of task loading is probably a reasonable value as Ohmart believes.

In an experiment reported by Hamilton (1958) comparative data for field and terrain model simulator studies for night vision situations were also developed but in this case, the variables were not well controlled. However, it is interesting to note that this second study resulted in longer acquisition ranges under field conditions, the opposite result to that found by Blackwell, Ohmart and Harcum.

A recent study by the Air Force compared the AMRL 1000:1 terrain model with actual field performance data for air-to-ground target acquisition performance at night using aerial flares (MacLeod, 1973). The target acquisition performance simulation study was conducted in detail on the AMRL terrain model. Results were then verified with limited field tests. Product-moment correlations between simulator and field test data were very good, ranging between +.90 to +.93. Hilgendorf (1973) also reviews in part the results of terrain table flare simulation data with field test and reports correlations of between +.77 to +.93 between the two for several variables, plus positive qualitative results.

6.4.4 Flight Test Studies

Research and evaluation of air-to-ground target acquisition performance can be obtained either from operational tests or from some form of simulation. The two approaches are really complementary. Field tests are certainly more realistic but simulation generally allows better experimental control. The majority of the work reviewed in this handbook is concerned with simulation or with laboratory experiments. Only a relatively few well controlled experimental field tests have been reported upon. This is due, of course, to the difficulty and expense of conducting valid tests in real world conditions. The target environment, usually, cannot be controlled. If a certain variable must be tested, then the conditions for that test must wait until the "world" is

correct. In many cases, this wait costs time and money, while the conditions may never appear during the time allotted for the test.

Possible sources of operational flight data include combat missions, training missions, and flight tests. Flight tests allow the most systematic collection of target acquisition data. Little information is available from combat situations, at least for research purposes. Such data are not normally published in unclassified documents and in any event the results are most often anecdotal. Combat data are most often of limited value in detailed study of factors affecting target acquisition performance. Target acquisition research is frequently concerned with the effectiveness of specific weapon systems still in the development stage. Even if the system is operational or the research is of a general nature, only a limited amount of information is available from records of combat missions. Certainly precise objectives, repeatable quantitative data about the nature of the target and background, and the conditions under which the acquisition task was carried out are unlikely to be reported.

Limitations in the use of data from combat missions also apply to routine training missions. In addition, pilots in training are unlikely to achieve the same performance levels as those who are fully qualified. Nevertheless some survey studies have used data from training missions. For instance, McGrath and Borden (1963) studied the records of 959 training missions to determine the extent to which geographic disorientation was a serious factor affecting mission success. They were able to use results of training missions. (This study did not consider target location accuracy, however.) In general, however, training missions have not been a fruitful source of data. Training is a primary mission and those responsible are usually reluctant to allow research and tests to interfere.

Flight trials to be effective should be conducted specifically for research with effective aircraft and ground instrumentation. Systematic flight trials, with a degree of experimental control, can be combined with a high level of operational realism to provide a link between operational situations and simulation experiments. Flight trials provide operational conditions for the cockpit environment, pilot work load, the effects of buffeting and vibration, a dynamic external visual environment, and atmospheric effects. The stress of flying over defended hostile terrain is not usually available in a flight test. In this respect, flight trials must be regarded as a form of simulation. The realism inherent in flight tests also often omits adequate experimental control and accurate measures of performance. Adequate experimental design and control is the big problem in field tests.

Good experimental design requires systematic changes in key variables while other effects on performance are held constant. Flight tests often do not allow this. Some conditions, primarily weather, cannot be held constant during a series of test runs. There are also other limits on

systematic variation and/or control, such as flight path, pilot and observer skill, number of targets, target-background relationships and target shape, size, and location. Finally, flight safety limits certain conditions and operational procedures which may be practical in combat operations.

Even a well designed, carefully controlled, and effectively executed field test still may not be completely successful. An excellent example is the field test of a visibility model conducted by the Navy and Scripps Institute in 1962 and reported by Erickson and Gordon (1970)[1].

The purpose of the test was to validate a visibility oriented target detection and recognition model. This effort was unique in the level of detail in measurement and in the computation involved, as well as being one of the few full scale field validations of a target acquisition model.

The model provided maximum detection ranges for two vehicle-type targets and, with some simplifying assumptions, provided estimates of maximum recognition ranges, where recognition was defined as being the ability to distinguish between the two targets (a tank and a van). Since the model is not currently used and did not prove to be practical, the details are not presented. The details involved in field testing and measurements, however, are unique.

Extensive field measurements of atmosphere and of vehicle visibility were made concurrently with test flights by A-4 pilots at China Lake, California. Most pilots flew more than one test run and an average of 2.8 flights. Target detection and recognition results obtained were then compared with the model predictions. Only search along a strip was involved since the target area location was defined by a graded strip in the desert. Two targets, a radar van and an M-4 tank, were parked in various positions along a long, narrow bulldozed strip. The pilots flew in at 270 knots IAS and at a prescribed altitude. "Detection" consisted of reporting that an object could be seen. "Recognition" consisted of reporting the type of vehicle and orientation. The van always pointed north, and the tank always pointed south.

The procedures used were as follows (Gordon, 1963):

1 Precise measurements of the targets' reflectivity were made. This included detailed data on reflectivity of the finish, as a function of wave length, angle of incidence of illumination, and viewing angle. Photos were taken under many conditions and were scanned with a densitometer to obtain contrast patterns of the targets.

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1 The tests were actually conducted by Louie Erwin who died before the results were published. Erickson compiled the data and published the NWC report in 1970 so that the information would not be lost (Erickson, personal communication, June 1974).

2 Similarly, precise properties of the soil and blacktop and background were also subjected to detailed study.

3 The "inherent target indices" were described by use of the detailed densitometer plots of the target from a given angle combined with the shape of the visual lobe of an observer. Convolution integrals of targer contrast and visual performance data were then used to produce a "target index" for each target for a given altitude and line of sight.

4 "Apparent" target indices were then devised. The inherent target index was multiplied by the transmittance of the atmosphere and the aircraft windscreen and modified by a "field factor" to obtain the "apparent target indices." (The model considered three field factors, 2.4, 3.6, and 3.8.)

5 The theoretical sighting range was then calculated. The ground range to the center, forward edge, and near edge of the assumed "hard shell" detection lobe was computed for each of several visual depression angles. The extent of ground range between near and far edges of the lobe represented the range with which detection could take place for that set of conditions. Figure 6-27 is a typical detection lobe plot.

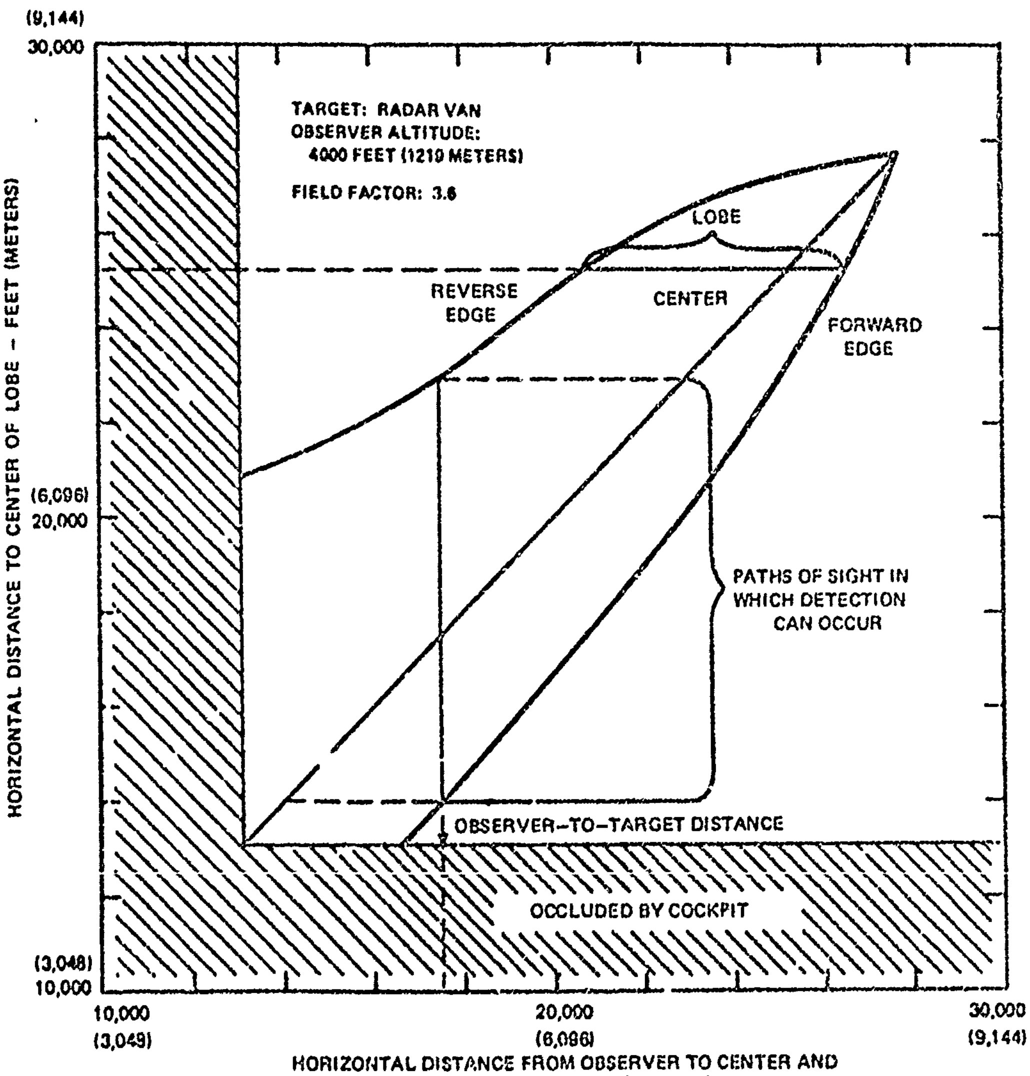
6 Calculation of detection probability was then made. A set of assumptions about pilot search behavior was made to permit selection of line of sight angles. Probability of detection in a single glimpse was determined. Cumulative probability was then computed on the assumption of systematic search. Figure 6-28 is a typical cumulative probability. The theoretical maximum range is degraded by the field factor.

7 A "target index for conditional recognition" was computed based on the assumption that the recognition response could take place as soon as the observer could detect the difference in signal between the two targets, and allowing a 2.7 second interval for study of the target. Thus, the predicted recognition range was simply 2.7 seconds of observer travel less than the detection range. This value was based on a study which simulated low level target acquisition by using small models as seen from a passing automobile (Duntley, 1957).

The modeling techniques proved to be very optimistic when compared with test results (Erickson and Gordon, 1970). In general, detection ranges were underestimated while recognition ranges were significantly overestimated. In this field test, search was not a problem; thus,

the underestimation of detection is not surprising. However, the results for recognition clearly indicate that more is involved in recognition than just simple, visual signal pattern differentiation. Compare the obtained results for cumulative probability of detection and recognition in Figure 6-29 with those predicted in Figure 6-28.

This report presents clearly the problems of field evaluation and validation. The results were much less definitive than was expected in spite of extensive, careful measurements, a superior, well planned and executed experimental design, and deliberately limited test objectives.



SOURCE: ERICKSON AND GORDON, 1970

Figure 6-27. Linear Definition of the Detection Lobe, and the Paths of Sight Appropriate to Detection at a Given Observer-to-Target Distance

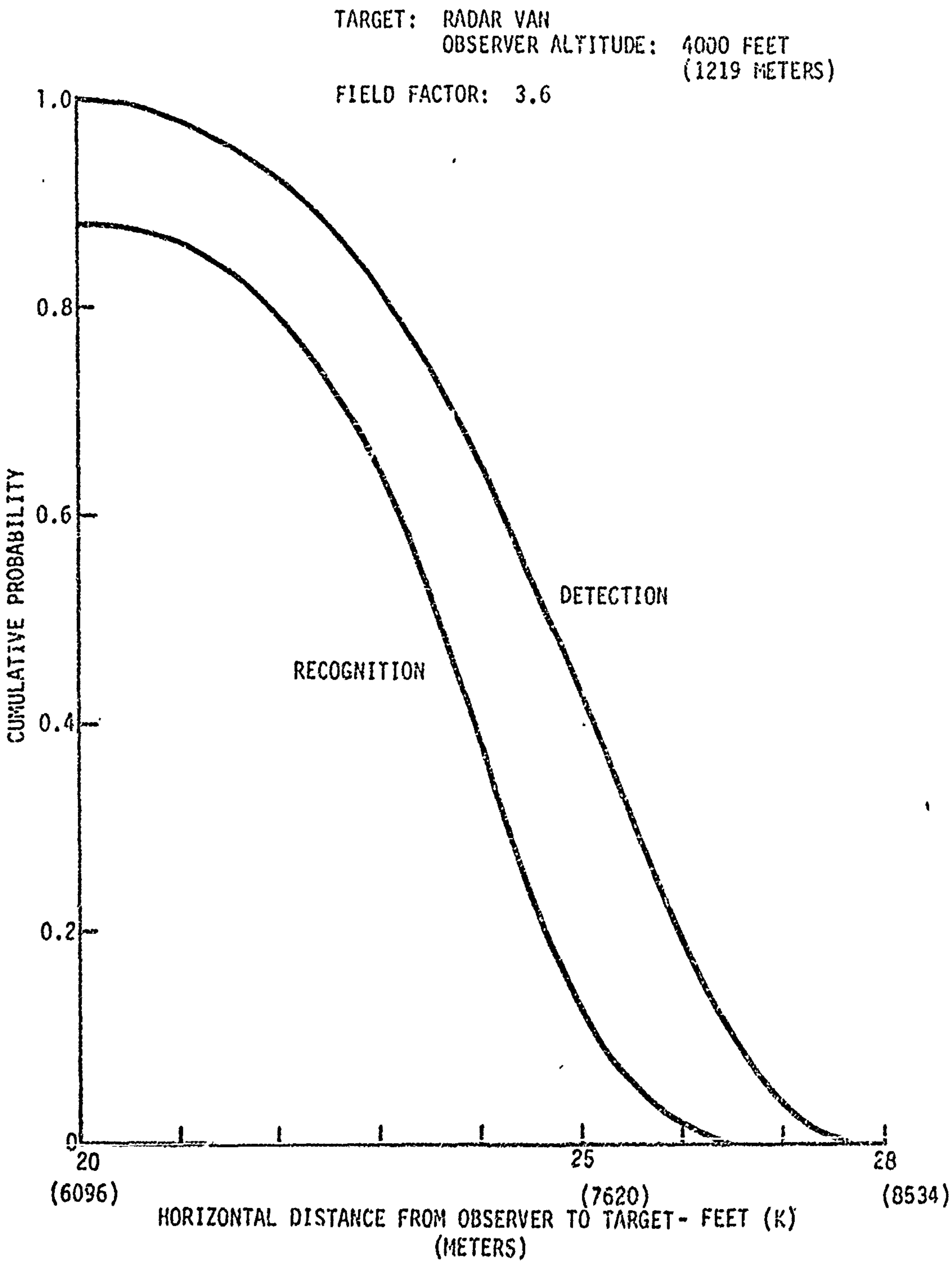
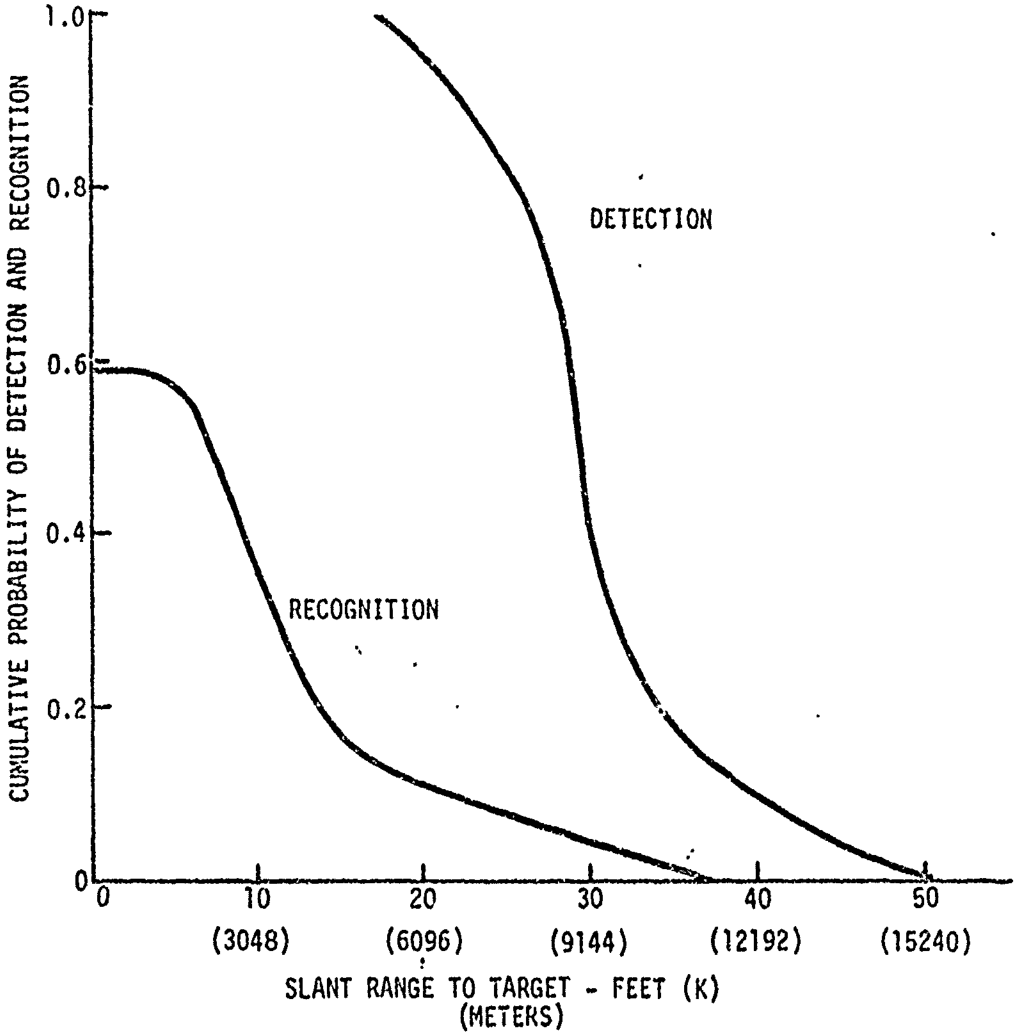


Figure 6-28. Typical Cumulative Probability of Detection and Recognition for Systematic Search for the Possible Target Positions at the End of a Bulldozed Strip



(ERICKSON AND GORDON, 1970)

Figure 6-29. Field Test Results, Cumulative Probability of Detection and Recognition of a Radar Van From 4000 Foot Altitude

Flight test performance may be measured in terms of target acquisition range. Here the correctness of the acquisition, and the actual range must be determined. Instrumented ranges can be used to provide radar, laser, or other range measuring data. Pilot reports of acquisition combined with true verified location on the ground and a film or TV record can be used to assure correct acquisition. In general, photo or TV recording provides the most reliable verification of target acquisition by a pilot. Using only verbal reports as to location or orientation of target does not allow for possible mislocations; even whole target areas can be mislocated (JTF-2, Tests 4.1 and 4.4). Vertical photography can also be used to provide aircraft location. For all key variables in the test, redundant measures are usually necessary. For example, Blackwell, Ohmart and Harcum (1958) report differences in acquisition range as measured by optical tracking and by vertical photography of 13 percent. Wade (1964) and Richardson (1962) also report similar discrepancies between measurement techniques. Range measurement must be precise and at least two independent measurement techniques are needed.

Any objective evaluation of field test data makes obvious the problems of measurement and control. A review of some field test results was conducted by Bliss (1966). Bliss, for instance, cites a report in which he states, " . . . (This test) illustrates the problems of conducting and reporting flight tests when thorough planning has not been done. There is no experimental design of any kind, no control of pilot ability, and no control of learning, no check or assessment of the accuracy of range measurements, no check on the validity of the pilot's detection and identification reports, no review of previous work on the same problem, and no statistical tests. A totally inappropriate altitude for search for these types of targets was selected. The report is internally inconsistent in description of procedures and draws conclusions not consistent with the reported results." Needless to say, Bliss is dubious about the validity of many field tests.

Another approach to field testing was that adopted by Joint Task Force Two (JTF-2). Here a major field test effort involved a dozen different types of aircraft, and five different classes of field tests, consisting of more than 3000 sorties. Two of the major tests series evaluated air-to-ground target acquisition, at altitudes below 1000 feet (304 m.). JTF-2 was established in 1964 by direction of the Secretary of Defense, directly responsible to the Joint Chiefs of Staff, to test the low altitude capabilities of tactical and strategic aircraft weapon systems, along with the capabilities of air defense systems against low flying aircraft. The test program was discontinued after 1967. Test 1.0, Minimum Terrain Clearance and Test 3.1/3.5, Surface-Based Air Defense are not directly related to this discussion. However, two of the tests were of target acquisition systems and the third was related to it.

Test 4.1, Visual Target Acquisition, examined the visual ground target acquisition capabilities of representative aircrews against pre-briefed targets, flying representative aircraft under visual flight conditions over rolling terrain. Also examined on the target acquisition task was the relationship between such variables as aircraft type, terrain clearance, altitude-target characteristics, and environment. Assigned test altitudes were two terrain clearance bands: minimum safe altitude to 400 feet, and 500 to 900 feet above the terrain. Ten aircraft types were used: five tactical strike (A-1E, A-4B, F-4C, A-6A, and F-105D), three tactical reconnaissance (RF-101, RA-5C, and RF-4C), and two strategic (B-52 and B-58). A total of 474 data gathering sorties was flown by the 232 participating aircrews at assigned airspeeds varying from 175 to 550 knots.

Test 4.4, Target Acquisition-Tactical Air Reconnaissance, evaluated aircrew, sensor, and interpreted target acquisition capabilities against targets of opportunity over rolling terrain. The target acquisition task examined the relationship among such variables as aircraft type, altitude, speed, course, and environment. Assigned altitude bands were from minimum safe altitude to 400 feet, and 500-900 feet above the terrain. Forty-nine field army type targets, all distinctly visible from the air, were used in the test. Aircrew performance was scored based on the percentage of targets acquired, how accurately the acquired targets were described, how completely the target complexes were described, and how accurately the targets could be located on maps. Photo interpreters were similarly scored. Sensor performance was evaluated as to the percent of targets and individual target details that were captured on imagery. Data were obtained from 508 A-6A, A-4C/E, F-4C, RF-4C, O-1E, and UH-1B aircraft sorties.

Test 2.1, Penetration-Operational Systems, was flown in conjunction with Tests 4.1 and 4.4. Navigation capabilities of representative aircraft and aircrews at low altitude over both flat and rolling terrain and over navigation courses ranging from 150 to 175 miles in length, were examined in this test. Navigation capability was measured by rate of check point acquisition and time deviation. The relationship among such variables as aircraft type, altitude, speed, and aircrew experience was also examined. Data were obtained from 478 sorties over flat terrain and 421 sorties over rolling terrain. While the navigation data do not directly involve target acquisition, the results of navigation uncertainty can affect operational target acquisition performance. (See Section 5.2.3.4.) Thus these results are also of general interest to the problem of target acquisition.

As part of the 4.1 and 4.4 field tests a series of photographic flights was conducted to obtain specialized wide angle 70 mm photographic simulation imagery for the support of task force research programs. Collection of Test 4.1 imagery was completed during the summer and fall of 1966, using the standardized field test courses established by

JTF-2 in the Louisiana/Arkansas/Oklahoma area. The test courses for Test 4.4 were established in the same general area and were filmed during the summer of 1967. The specific flight and photographic conditions used in filming were deliberately selected to meet particular JTF-2 simulation test requirements. In general, separate films were collected to represent systematic variations in those flight parameters dependent on aircraft position (i.e., altitude and offset). Each simulator mission film represented coverage of a particular JTF-2 test course under a specified set of operational conditions. In addition to the motion picture films, imagery using infrared and radar sensors, and oblique and panorama still photographs were obtained. The simulation phase was not conducted, however, due to the disestablishment of JTF-2.

The majority of the JTF-2 test data is classified and/or still retains a limited access status. Thus a discussion of the results is not possible here. However, the test series represented the best efforts of military and scientific personnel to obtain statistically valid and operationally useful data. The test designs were such that statistically sound samples of human performance data were planned. The quality and quantity of information as to target acquisition performance were compared with ground truth. The accuracy of performance in acquiring targets was measured and the accuracy of those measurements reported. The available JTF-2 results have been noted in previous chapters in this source book. The JTF-2 results contradict none of the major findings previously noted herein. The data are reported in a series of JTF-2 volumes cited in the bibliography.

Another series of field and simulator tests of air-to-ground target acquisition is being conducted under Department of Defense sponsorship as project SEEKVAL (Joint Test Project, July 1973). Some initial results of simulation studies in this program have been cited (Van Arsdall, 1974, Freitag, Hilgendorf and Searle, 1974). As of this date, however, no field tests have been conducted.

A recent summary of field test data has also been prepared by Thornton, Erickson, and Bruns (1973). This classified document summarizes 54 reports of field tests of direct visual air-to-ground target acquisition. The authors found that the reports were not well organized. As a result, meaningful, related data were hard to extract. Typically, many reports were deficient in descriptions of test conditions and procedures. Such key data as range of target acquisition were often not reported. Even where it was, the definitions of the target acquisition process used in the test were not the same. (See Glossary of this sourcebook.) While many excellent tests were noted, most field tests were poorly structured and poorly reported. Table 6-IV is from the report by Thornton, et al (1973). This summary indicates the contents and limits of typical flight tests. Table 6-V is adapted from that form and modified to include sensor aided as well as direct visual target acquisition tests. Tables 6-IV and 6-V provide a preliminary check list for the presentation of data in flight tests of target acquisition.

TABLE 6-IV

Test Completeness Statistics

SOURCE: Thornton, et al (1973)

Total of 57 Reports/Tests Reviewed (4% were not applicable)

Of the 53 applicable reports/tests, the following percentages apply:

TYPE OF DATA PRESENTED:
- Range to target at task completion - 56.6%
- Percent of targets where task completed - 30.2%
- Time required to perform task - 24.5%
- Probability of completing task - 16.9%
- Errors (e.g., false reports) - 16.9%
- Cumulative probability as function of range - 15.1%
- Number passes required to perform task - 1.8%
- Other types of data (or data of little use) - 11.3%

TARGET CONSIDERED:
- Type:
  - Vehicle - 45.3%
  - Personnel - 9.3%
  - Deployed army - 45.3%
  - Convoy - 16.9%
  - Other - 15.1%
- Number per configuration:
  - One - 30.2%
  - Two - 3.7%
  - Three - 15.1%
  - Four or greater - 11.3%
  - Varied - 20.7%
  - Not reported - 18.9%
- Movement:
  - Static - 90.6%
  - Dynamic - 37.7%
- Aspect and orientation (w/r to flight path) reported: 52.8%
- Lighting (direct sun/shade) reported: 39.6%
- Luminance (and/or reflectivity) reported: 3.7%
- Glint/highlights reported: 1.9%
- Amount of camouflage:
  - None - 45.3%
  - Some - 30.2%
  - Not reported: 24.5%
- Contrast reported: 13.2%
- Color reported: 28.3%

BACKGROUND:
- Search area size reported: 52.8%
- Terrain/foliage information given: 75.5%
- Clutter/cue information provided: 58.5%
- Luminances (and/or reflectivity) reported: 11.3%
- Lighting reported: 43.4%
- Colors reported: 9.4%

AIRCRAFT:
- Type:
  - Fighter - 32.1%
  - Observation - 26.4%
  - Bomber - 11.3%
  - Helicopter - 30.2%
  - Attack - 13.2%
  - Other - 15.1%
- Flight Tactic:
  - Straight in - 54.7%
  - Combination - 9.4%
  - Dive - 1.9%
  - Pop-up - 9.4%
  - Orbital - 3.8%
  - Not reported - 26.4%
- Altitude (feet):
  - Pop-up or nape-of-the-earth - 18.9%
  - 0-400 - 41.5%
  - 400 - 1000 - 49.1%
  - 1000 - 2500 - 39.6%
  - 2500 - 5000 - 32.1%
  - 5000 - 8000 - 18.9%
  - Greater than 8000 - 13.2%
  - Not reported - 3.8%
- Speed (knots):
  - 0 - 50 - 16.9%
  - 50 - 100 - 24.8%
  - 100 - 250 - 26.4%
  - 250 - 400 - 32.1%
  - 400 - 550 - 30.2%
  - 550 - 700 - 5.7%
  - Not reported - 20.8%
- Other flight path information (e.g., heading) reported: 47.2%
- Number of aircraft in group:
  - One - 86.8%
  - Two - 5.7%
  - Three - 7.6%
  - Not reported - 3.8%

Geographic orientation to target reported: 28.3%
Vectored to target area:
- Yes - 26.4%
- No - 24.3%
- Not reported - 28.3%

Requirement to navigate to target:
- Yes - 43.4%
- No - 41.5%
- Not reported - 15.1%
- Accuracy of approach to target reported: 35.9%

CREW:
- Number searchers per aircraft:
  - One - 81.1%
  - Two - 24.5%
  - Three - 3.8%
  - Four - 1.9%
  - Not reported - 3.8%
- Experience (e.g., pertinent flight hours) reported: 67.9%
- Type of briefing subjects received reported: 66.0%
- Familiarity of crew with area:
  - Familiar - 20.8%
  - Varied - 3.8%
  - Not familiar - 1.9%
  - Not reported - 73.6%
- Number previous passes in test reported: 32.0%
- How much general flying in area reported: 5.7%
- Specific information on crew:
  - Rank reported - 30.2%
  - Age reported - 11.3%
  - Test scores reported - 13.2%

TASK:
- Detection - 66.0%
- Recognition - 52.8%
- Identification - 37.7%
- Other - 9.4%
- Definition of task given: 73.6%
- Search tactic used reported: 15.1%
- Workload (other than searching):
  - Yes - 69.8%
  - No - 45.3%
  - Not reported - 3.8%
- Search time available reported: 37.7%

ATMOSPHERE:
- Inversion/haze layer reported: 15.1%
- Visibility reported: 49.1%

How visibility measured reported: 28.3%
Cloud cover level reported: 39.6%
Ceiling condition reported: 28.3%
Sun angle (w/r to line-of-sight to target) reported: 30.2%
Wind speed correction reported: 3.8%

TABLE 6-V

FIELD TEST REPORT ON AIR-TO-GROUND TARGET ACQUISITION

DATA SUMMARY FORM

REPORT TITLE AND NUMBER

Field Test:

Technical Performance:

Issuing Agency, Date, and Author(s):

Type of EO System:

TYPE(s) OF DATA PRESENTED

Range to target at task completion

Probability of task completion

Time required to perform task

Number of passes required to perform task

Errors (e.g., false reports)

Range of lock-on

How target acquired

A. EO only   B. EO, confirmed by Direct View

C. Direct View, Switch to EO

Time to (A)   (B)   (C)

Time to complete task

Other

TARGET (SPECIFY BOTH MILITARY AND VISUAL ASPECTS)

Number/configuration

Type (and/or size, shape, etc.)

Moving or Static

Aspect and Orientation (w/r to 3-D flt. path)

Lighting (direct sun/shade)

Color

Luminance (and/or reflectivity)

Glint/Highlights

Camouflage

Contrast at Target

at Sensor

at Display

Temperature

BACKGROUND - - SEARCH AREA SIZE

Terrain/foliage classification

Clutter/cues

Lighting

Colors

Luminances (reflectivity)

Temperature

AIRCRAFT - - TYPE

Flight tactic (straight-in, orbital, etc.)

Altitude

Speed (ground speed if possible)

Other flt. path info. (e.g., heading, position)

Number A/C in group

Geographic orientation in approaching target area

Vectored to target area?

Requirement to navigate to target

Accuracy of approach to target

CREW - - NUMBER SEARCHERS PER A/C

Experience (pertinent flight hours)

Type of briefing received

Familiarity of crew with area

Number previous passes in test

How much general flying in area

Specific info. on crew: Age

Rank

Test Scores

Experience with System

Number Observers per Display

SENSOR

Type

Where carried

Field of View in Degrees

Fixed

Variable

Zoom

Scan Angle

LOCATION:

Missile | Pod | A/C

TRACK:

Manual

Automatic | Type

Resolution

Comments

DISPLAY

Type

Size

Resolution

Display Quality Measure

Viewing Distance

Ambient Illumination

Hood

Special Features

Comments

TASK - - Detection, Recognition, Identification, Classification

Definition of above used

Search tactic used (uniform, line, random, etc.)

Workload (e.g. navigating and searching)

Search time available

Search Tactic

ATMOSPHERE - - INVERSION/HAZE LAYER

Visibility (subject-to-target?)

How measured

Cloud cover level

Ceiling

Sun angle (w/r to line-of-sight to target)

Wind speed correction

Humidity

REMARKS - - EVALUATION OF TEST, ETC.

6.5 Conclusion

Techniques available for the evaluation of air-to-ground target acquisition performance vary widely in the extent to which they accurately represent the visual and dynamic complexity of the real world task, in the degree to which the experimental situation can be precisely controlled, and in complexity and cost. Each of the three main techniques, mathematical models, visual simulation, and field tests, has particular advantages and disadvantages which must be closely considered when selecting an evaluation method.

Operational data represent the maximum possible realism. But flight tests can only provide reliable information if the trials are carefully planned and conducted so as to ensure adequate experimental control. Even when this is done, the variability of the data is inevitably large, as compared with data obtained under conditions of more rigorous experimental control. Blackwell, et al (1958), Gilmour, et al (1969), Valentine (1971), and Thornton, et al (1973) all report variability of flight trial data up to three times as great as that of corresponding simulator trials. To achieve the same level of statistical significance, therefore, a much greater number of trials are required. In practice this is very rarely possible since flight tests are expensive in terms of both personnel and equipment, as well as time.

In view of the difficulty and expense of obtaining flight data, the use of simulation is an important way to evaluate target acquisition performance. A number of sophisticated techniques have been developed for the simulation of the terrain viewed either directly by motion pictures, or by means of a television system. Accurate visual simulation is a primary requirement in target acquisition evaluation. The degree to which other aspects of the operational situation, such as environmental effects or aircrew workload, must be represented in order to obtain valid data, has not been clearly established. Thus, even if the simulation has been well defined, determining the extent to which the operational situation should be represented is by no means easy. The more the simulator test approaches the real world, the greater the complexity and cost of the equipment required. In theory, the aim must be to maximize the validity of the data obtained while minimizing the complexity and cost. In practice there are few guidelines as to how this can be achieved. Careful experimental design and specification of variables to be tested are vital. However, better control of experimental conditions is possible with a simulator.

In some cases a decision may be made not to simulate but to abstract certain aspects of the test and study them in isolation, in order to obtain information about the basic processes involved. This "laboratory" method has the advantage of reducing the cost of the equipment and allowing

greater control over the variables of interest. The data obtained from these simplified situations are not readily related to real world conditions. Laboratory simulation in which the visual complexity of the operational task is reduced by the use of simple abstract displays or the dynamic complexity eliminated by the use of static material, can make a valid contribution to the study of target acquisition problems but such an approach can only be regarded as complementary to, and not a substitute for, more realistic simulation studies.

A different problem usually also encountered at an early stage in the development of a system, is determining the conditions under which satisfactory performance cannot be achieved so that they can be eliminated from further consideration. Evaluations of this sort can be effectively carried out by means of mathematical modeling techniques. Since most models tend to be more optimistic than operational conditions, it can be assumed that if acceptable performance cannot be achieved in the model, then the system will also be operationally unsatisfactory. Thus, modeling allows minimum standards to be established at an early stage in the development program for a target acquisition system.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Purpose

T e purpose of this chapter is to summarize the problems and shortcomings in target acquisition (TA) work and to recommend areas in system design, operations, and research which have some probability of providing answers to the problems of acquiring targets. This source book has reviewed the results of experimentation, simulation, models, theory, and the results of field studies pertaining to air-to-ground TA. The bibliography of approximately 1750 references accumulated as a direct outcome of the literature search necessary to prepare this report indicates the enormity of the field, the wide number of technology areas contributing to it, and the large number of individuals actively pursuing solutions to its variety of problems. The results of this search have been disappointing in some ways. There is no straightforward way to select appropriate data from laboratory, simulator, or field tests and to combine the whole into a sensible, comprehensive view of TA.

Early in this discussion, a classification scheme for the TA problem was chosen (Figure 1-2). To a large extent this approach has been followed throughout this review. The effects of uncontrolled variables even under the same nominal conditions have been noted. The impact of interactions between those variables has received less emphasis. For simplicity, the review of this data may have tended to ignore the complex effects of interactions among the events that affect TA. The parameters and variables noted in Figure 1-2 do not usually act independently. The level of detail in which they are considered is not consistent in any two studies. If all the variables were always measured in the same way and were always reported, some reasonable evaluation of interactions might be made. Obviously this has not happened. The number of variables is large, and many are not amenable to control. Even the choice of important variables will depend upon the bias and interest of the investigator concerned. However, based upon our review of published material and the authors' biases and interests, the conclusions are presented in this chapter.

The following general criticisms and conclusions of TA research seem to be appropriate at this time:

1. No simple answers to the description, evaluation, and prediction of TA performance exist at present, nor does it appear likely that major breakthroughs will be soon forthcoming.

2. Although much laboratory research has been performed in search, detection, and recognition of targets, most of it has used abstract targets and backgrounds, has had a research, rather than applied, bias and slant, and is at best, not directly applicable to solving the applied TA problem(s).

3. There has been some ill conceived, poorly organized, and badly executed work in the area of TA, particularly in field test and simulation where important variables have not been identified, measured, or held constant.

4. Insufficient work has had a human performance orientation, investigating the effects of learning, motivation, and individual differences.

5. The literature of TA is, for the most part, difficult to obtain, collate, and review. Much of it is buried in company files, out of print, or otherwise not in the open literature.

6. A problem plaguing the TA area is the lack of a standardized nomenclature, definition of terms, measurement methodology, and mathematical symbology.

7. There has been little communication between practitioners and researchers, probably because of the lack of understanding of practical problems, and because of differences in training, background, and methodology.

8. There has been some polarization but little cooperation among the different technologies concerned with TA, e.g., the display group interested in display quality and the mission-analytic group interested in task and mission parameters.

9. A problem inherent in simulation studies has been the lack of a simulated atmosphere. This probably is one of the causes of the disparity in the results of these studies with those of flight or field tests.

10. A major problem with field testing has been the lack of a satisfactory measurement of atmospheric attenuation (visibility) concurrent with the acquisition runs or missions.

11. Some areas of TA have been neglected because good techniques for simulation or measurement have not yet been devised. Shadows, contrast, and effects of camouflage and atmospherics (haze, smog, fog, etc.) are examples of this neglect.

12. Some concepts such as "resolution element" need a better operational definition if measurement and modeling efforts are to improve the accuracy of prediction.

13. The validity of terrain table simulation must be established. A problem of concern, for example, is the effect of two versus one eyeball in terrain table work. This problem can be decided once the importance of stereoscopic factors is determined in viewing terrain tables at different viewing distances and scales. Another problem is the effect of dynamic versus static viewing and mission simulation, and of fixed versus moving base simulation. Once the relative effects of these factors are determined, the validity of terrain table simulation will be improved.

14. The apparent face validity of motion picture simulation requires effective evaluation. What are the real requirements for viewing angles? Is use of wide angle photography necessary? How does resolution and MTF of the camera lens system relate to TA performance? And how does real world, real-time performance relate to motion picture simulation?

15. In the area of search, more work should be performed on the characteristics of "good" searchers versus "poor" and, on organized trained search versus random. Definition of these variables will help to obtain a better model of the search process and hence of prediction. Also needed is the effect of terrain background compared to homogeneous backgrounds (or free-field search). Finally, a reasonable, well validated mathematical model of visual search is required.

16. The "fudge" factors used to bring the laboratory data on contrast thresholds into the operational acquisition realm are based on inadequate data and hypothesis. They need to be validated by proper simulation or field study using realistic scenic backgrounds and task conditions.

17. Although there is a plethora of mathematical models, no one model has the answer to the target acquisition prediction problem. More work needs to be done in validating them and finding out where they can be best applied. The answer to this problem may lie in validating submodels rather than the entire process.

18. The MTF approach is a concept entirely useful to engineers, psychologists, physicists, and meteorologists. This approach merits expanding and further development into a systems concept.

The foregoing discussion notwithstanding, there are many positive factors that can be gleaned from the TA studies. The remainder of the chapter will discuss these findings and their implications. As in any summary, simplifications may not satisfy the specialist. What is obvious to one individual may not be so to another. The responsibility for deletion or inclusion is the authors'.

7.2 Applications

The parameters outlined in Figure 1-2 will be noted and the effects the factors may have will be cited as: 1) design recommendations, of interest primarily to the systems engineer, 2) operational implications, of interest primarily to military operations personnel, and 3) research required, of interest primarily to scientists.

What is important for one of these three areas may not necessarily be important for another. Further, the diversity of results between laboratory research, simulation studies, and field tests makes it hard to develop quantitative summaries of TA data. It is possible to make certain qualitative summaries which are supported by the data. In many cases, however, these statements appear to be mere elaborations of the obvious. Wherever reasonable a qualitative approach has been taken, recognizing that this approach, while scientifically "incorrect," is pragramatically "necessary." Engineers and operators need answers; researchers want more time to study the problem. The following are logical extrapolations based upon data developed in previous chapters.

7.2.1 Target Background Parameters

7.2.1.1 Design Recommendations

1. Optimize the system design for a class or type of target. A system for acquiring air fields is useless for finding tanks, for example.

2. Provide at least 5 arc minutes visual angle for reliable target detection. The crucial size of a target is minimum visual angle at the eyeball of the observer; the larger object is acquired first.

3. Provide at least 10 arc minutes visual angle (30 desired) at the eye, if the observer is required to reliably recognize or identify a target. The task of identifying a target depends upon the ability to determine differences in shape and other detail about the target.

4. Provide at least 20 percent apparent target-to-background contrast at the eye of the observer for target acquisition. Above about 35 percent apparent contrast, there is little improvement in TA performance. The absolute practical minimum threshold is 5 percent contrast.

5. If a trade is required, first maximize for contrast, then size, and finally shape.

6. Designing to use natural color is unnecessary. Natural color, either in direct view or on television, is a relatively unimportant aid to finding targets. An exception is intensely saturated hues on a homogeneous background.

7. A TA system which provides the observer with a reliable cue as to where to look is preferred, perhaps even necessary. Almost any cueing device - motion detector, spectral analyzer, laser spot seeker, relative aircraft to target predictive information - will significantly improve target acquisition capability.

7.2.1.2 Operational Implications

1. Targets are part of a complex of target and background. The background is as important in helping acquire targets as the target. Thus a target which is distinguishable from the background is easiest to find.

2. Use distinctive features to help locate a target. If the target is not conspicuous, then other objects near it may be located and the target related to these objects.

3. Things that make an object stand out include:

   a. Differences in type, e.g., tanks are obvious in a group of trucks.

   b. Size; obviously big objects are easier to find than small. Small size objects (below 5 arc minutes at the eye) will be acquired only if they have high contrast with the background.

   c. Shape, man made or straight lines stand out in natural backgrounds. Distinctive shape is an aid in acquisition. Shape is less important than contrast or size.

   d. Luminance contrast; bright objects are easiest to see - the practical lower limit for contrast at the eye is 5 percent. Objects much below 20 percent contrast are not usually acquired. If it is necessary to find a low contrast object, then sufficient time to search (up to one minute or more) must be provided.

4. Color is not very important except for unusually highly saturated or brilliant colors.

5. Moving targets are easier to acquire. Relative motion of the target is not as important, however, as are the cues the motion provides, e.g., dust, ship wake, changing contrast of the moving target with its background.

6. Shadow provides a change in the relative shape and contrast of the object. Thus effects of shadow are differential, depending upon the target-background complex. In open areas shadow generally is an aid; in cluttered areas (trees, buildings) shadow is confusing. In hilly terrain shadow acts to hide targets.

7. Terrain and vegetation act to mask targets. In rough terrain and/or heavily vegetated areas the time that the target is unmasked from view can severely limit search time. If a target is masked repeated passes may be necessary to accurately locate it.

8. Objects of similar size, shape and/or contrast to the target in the area around the target act as clutter. The practical limits to a cluttered area is about four diameters in size relative to the target size. Allow up to ten times the normal search time (see 7.2.5.2) to acquire a target in a cluttered area.

9. Cues to target location in the backgrou d aid in acquiring targets by directing the observers' attention a to where to look. Good natural cues include:

   a. Linear objects - roads, railroads, rivers, - and natural intersections of linear objects such as road-rail and road-river crossing, ridge lines, tree line, etc.

   b. Homogeneous spaces in which no target of a specified type is expected, such as open fields, lakes, solid forested areas, etc.

   c. Large objects, usually with high contrast or regular shape such as warehouse buildings, farm buildings, storage tanks, airfields, etc.

   d. Numbers of target objects, a group of vehicles, three or more, is more easily acquired than one or two.

7.2.1.3 Research Required

1. Optical characteristics of targets and backgrounds should be specified, measured and catalogued.

2. A simple, practical method of directly measuring apparent target to background contrast in real time from the aircraft is needed.

3. A standardized definition of contrast is required.

4. Determine how much of the background area contributes to contrast with the target.

5. Develop an operational classification of terrain-vegetation-background types. Then develop standard visual target acquisition search time and acquisition range data for each classification.

6. Develop effective operational measures of clutter and the effective practical size of a "cluttered" area as related to target size.

7. Effects of camouflage have not been reported. More information and data are required.

8. Study the effects of shadows on target acquisition, i.e., when shadows help and when shadows hinder.

9. Develop a single operationally practical mathematical description of the target-background complex and/or context.

7.2.2 Aircraft Parameters

7.2.2.1 Design Recommendations

1. Obviously, optimize the aircraft sensor-observer combination for the target acquisition task at hand. Personnel, for example, are not reliably visually acquired at altitudes above 600 meters.

2. For visual target acquisition provide maximum practical viewing and look-down angles.

3. Good navigation accuracy usually means better target acquisition. Provide a means of accurate aircraft location up to date in real time.

4. Two observers are better than one; however, the two observers will find up to only 40 percent more targets, not twice as many as one observer.

7.2.2.2 Operational Implications

1. There is an optimum altitude for target acquisition depending upon target size and atmospheric visibility. "Under best conditions of visibility it is on the order of 250 times the linear size of the object being sought; under the worst conditions of visibility, it is on the order of 30 times the size of the object being sought." (Boynton in Morris and Horne, "Visual Search Techniques," 1960, p. 238).

2. The slant range at which a target is first visible should be calculated. Detailed search for that target before the maximum available range is unnecessary. The maximum visible slant range depends upon, at least:

   a. Relative target size; allow at least 2 arc minutes at the eyeball for maximum possible detection ranges.

   b. Atmospheric visibility.

   c. Target unmask at altitude.

3. Aircraft speed affects search time. For target acquisition choose the slowest practical speed from the time the target is theoretically visible.

4. Select routes of approach to minimize target offset from the aircraft (observers') most direct line view of the target. Good navigational accuracy should minimize target offset.

5. Select routes of approach to maximize target exposure time to the observer. If the target must be masked or hidden so that only minimum target exposure time is available, provide briefing, navigation and cueing aids to aid the observer in where and when to look. Under even these ideal conditions (i.e., knowing exactly when and where to look) the target must be exposed for at least 3 seconds; at least 10 seconds is preferred for reliable acquisition (better than 0.50 probability).

6. For the task of visually acquiring targets the aircraft providing best forward and look-down visibility is preferred. In general, observation from the front or forward seat is best for target acquisition.

7. If practical, providing more than one observer will improve total target acquisition probability by up to 40 percent per observer, when observers search the same area.

8. Moving targets are (slightly) easier to find than static ones.

7.2.2.3 <u>Research Required</u>

1. The Boynton hypothesis regarding altitude (7.2.2.2) needs operational verification.

2. The interactions of altitude, range, speed, and offset require more precise mathematical description. It is probable that these are not simple additive, geometric relationships but are at best represented by some polynomial function.

3. Validate the Dugas and Petersen (1971) laboratory study on target motion in terrain simulator and/or field test. At the same time verify the Erickson (1965) theory regarding relative motion.

7.2.3 <u>Environmental Parameters</u>

7.2.3.1 <u>Design Recommendations</u>

1. Develop and test new devices for characterising the environmental characteristics pertinent to TA, devices such as transmissometers, optical attenuation measuring devices, optical scattering and absorption measuring equipment. These devices should relate to the atmospheric characteristics which determine TA slant ranges and probabilities.

2. Develop better map making techniques and visual aids which can be used to acquaint the observer with the characteristics of the

ground; assist in orienting him relative to major landmarks. These can be used to improve briefing materials and the process of briefing observers so that the observer can better pinpoint target locations. These might include better perspective oblique photographs or artists' conceptions of areas where masking may be a problem, possible shadow effects, etc.

3. Develop automatic (computer-aided) TA equipment which will assist the observer possibly by using an MTF approach, by eliminating unlikely areas to be searched, by acting as a memory aid, or by information processing techniques.

4. Develop better methods of simulating atmospheric degradation effects for improving our abilities to simulate real-world atmospheric and climatological conditions. These methods may be extensions of aerosol chambers or by MTF control and simulation by filters, etc.

5. Develop methods and hardware for "unburdening" the pilot-observer so that he may devote more time to searching for targets and less to system monitoring and control of acquisition equipment, flight-control or navigational subsystems.

6. In flare design, provide consideration of the amount of illumination that can be used by the observer, maximize burn time and spectral characteristics, and minimize glare.

7. Continue to develop low-light or night-time techniques and equipment as aids to direct visual search. Continue to develop wide-angle optics for search and zoom-optics for recognition/identification aids.

7.2.3.2 Operational Implications

1. Adjust operational search and mission plans to the type of terrain being searched so that available search time is maximized, i.e., select search plan to be flown, search altitude and flight speed so that masking of terrain and of aircraft is minimized. These search plans should of course take into consideration the possible counter-survaillance measures available to the enemy where these are known.

2. Adjust mission or search plan or time of search to obtain sun or illuminant angles which provide the highest probabilities of detecting targets. Put the sun "at your back" if possible and put the flare in back of the expected enemy position.

3. Teach pilots and observers how best to search for targets in different terrain, likely target areas, scanning patterns, cues to target location search. Develop ability of search personnel to

react to cues which indicate target: man-made features, tracks, dust, smoke, foliage changes, etc. Teach observers to "narrow" search by ignoring clutter by use of lobe concepts or by visual aids such as tachistoscopes, apertures, etc.

4. Teach pilots what to expect in the way of target masking, effect of illumination, shadows, type of terrain, atmospheric conditions, etc. This may be done with the assistance of training aids, simulation, or by acquiring an extensive set of photographs with varying terrain type, clutter, and atmospheric conditions. These photographs could be related to particular terrain areas in which the pilots will operate and to visibility, climatology, cloud conditions, and atmospheric condition (haze, fog, smog, etc.).

5. Apply tests for selecting "good" or talented target acquisition personnel such as the embedded figures tests.

7.2.3.3 Research Requirements

1. Improve the models relating to masking, atmospheric conditions, and clutter so that mathematical models predict better the results of field tests.

2. Improve simulation capability by investigating the methods of simulating atmospheric conditions by means of aerosol chambers, MTF manipulation or filters.

3. Determine the effect of glare and sun angle on target acquisition slant range and probability.

4. Further investigate the effects of shadows on TA capability with various types of terrain and atmospheric conditions.

5. Investigate different methods of camouflaging targets and other countersurveillance techniques.

6. Develop "cueing" techniques to assist observers using helmet-mounted displays or heads-up displays.

7. Develop better atmospheric instrumentation techniques and atmospheric modeling.

8. Improve and validate "field factors" which allow better use of laboratory threshold data and better application and hence refinement of our predictive and analytic techniques relative to field conditions: instructions, training, clutter, terrain masking, and atmospheric conditions.

7.2.4 Sensor-Display Parameters

7.2.4.1 Image System Characteristics Design Requirements

1. A cockpit-mounted display should subtend at least 9 degrees at the eye of the observer for optimum viewing.

2. Viewing distance should be maintained as close to 14 inches as possible when a cockpit mounted display is used to detect targets.

3. Signal to noise on the display should be at least 1.8:1 (between 16 and 25 dB). The highest SNR_{DI} possible should be provided the observer at the display.

4. MTFA (Modulation Transfer Function Area) should be maximized to obtain the highest image quality obtainable.

5. Display contrast should be maintained at a medium level (8:1) for most TA applications, but should be adjustable by the observer.

6. At least 7 shades of gray should be obtainable at the display of the terrain if possible; 10 should be the design goal.

7. Ambient display illumination should be optimized without glare or reflection from the display surface.

8. Vertical and horizontal resolution should be comparable (equal).

9. As many TV lines across the target at the expected detection/recognition range as possible should be provided, at least 2 for detection and 8 for recognition and 12 for identification are the absolute minimum; double these numbers if desired.

10. Sensor field of view should be adjusted to the primary tasks that the imaging system is expected to perform: a small FOV, 1 to 5 degrees for recognition/identification, and a larger FOV, 5 to 30 degrees for detection. Although a dual FOV is recommended for a TA system expected to perform both detection and recognition/identification, a step or zoom or adjustable FOV system might be more adaptable albeit more expensive and should be considered via a system effectiveness tradeoff analysis. If practical, step adjustment is as effective for observer use as is zoom.

11. Combined displays are recommended using multiple sensors and an overlay type of combined display.

12. Display parameters should be optimized for the mission to be performed by the system: frame rate, bandwidth.

13. Every effort should be made to make the raster invisible or at least less visible than present systems. This can be done by spot wobble or by other techniques.

14. Wherever possible, systems should be tested in actual TA tests during development or at least prior to system acquisition. Laboratory tests are too abstract and it is difficult to simulate actual conditions of flight.

15. Image enhancement techniques such as edge sharpening or optical filtering should be used including gamma correction, contrast stretch, edge differentiation and multiple-sensor and multiple spectral bandwidth techniques.

16. Wherever possible, the display should be isomorphic with an out-the-window view of the terrain so as to avoid problems of direct visual/display visual transfer and to avoid disorientation effects such as scene rotation, disorientation, dizziness (vertigo) or airsickness. Gimbal arrangement or sensor control mechanisms or display techniques should be used wherever possible to provide stability of display and the required isomorphism.

17. The display and the pilot should be shock mounted or otherwise isolated from aircraft vibration forces wherever possible. This is particularly important in helicopter systems, as a predesignation technique (against fixed targets whose position is known).

18. Where missions are to be flown at low altitude, high speed or both, provide display freeze to allow the necessary time to acquire the target, by preventing blur from wiping out usable resolution on the display. Give the "freeze mode" to the operator as an operational option.

19. Provide cockpit illumination control so that the pilot or observer can adjust the ambient illumination to provide the most comfortable display, seeing fatigue-less viewing conditions.

20. Unburden the pilot or operator so that he can spend the maximum amount of time searching for targets on his display.

21. As an absolute minimum, at least 10 seconds of search time should be provided by the TA system (target travel from top of display to bottom) for non-cued targets, and at least 3 seconds should be provided for well-cued target detection/recognition. Triple those values is desired.

22. Displayed image motion should not exceed 20 degrees per second; 10 degrees per second is preferred as a better maximum rate of motion.

7.2.4.2 Operational Significance of Image System Characteristics

1. Missions should be planned around the optimum capability of the sensor/display with regard to altitude, speed, search pattern so as to maximize the probability of detecting targets.

2. Operators should be carefully trained in the operation of the TA system so as to know its shortcomings and advantages with regard to target size, contrast, etc., interactions with display characteristics, and mission parameters (speed, altitude, search pattern).

3. Operators should be trained in "peaking," i.e., adjusting the sensor and display controls for optimum display capability and highest probability of detection/recognition. This includes setting of contrast, illumination levels, focusing, etc. They should be trained in display scanning techniques so as to maximize early detection and reduce the number of lost targets to a minimum.

4. Mission plans should not exceed maximum V/H of the TA system or display blur will make the display virtually unusable.

5. Excessive vibration of the operator/display should be avoided where possible; this means avoiding excessive turbulence or adverse weather conditions, or postponing search missions to a more favorable time (again if operational conditions permit) or selecting a different speed/altitude combination.

6. Operators should be trained to select FOV (if the system has this capability) most favorable to TA depending upon flight parameters and targets being sought.

7. Operators should hold their viewing distance to the optimum (14 inches) where possible in order to maximize the resolution properties of the eye.

7.2.4.3 Research Recommendations

1. Additional research is needed in the utility as summary variables of MTFA and SNR_{DI}. In particular these summary variables should be correlated with the results of field testing and simulation, i.e., with performance variables such as slant ranges at detection/recognition and with the number of targets not found.

2. Interaction effects between display variables of contrast, shade of gray and ambient illumination should be determined as factors in TA dependent variable determination.

3. Better methods of determining and measuring MTFA and SNR_{DI} should be devised so that they can be standardized and made routine in research and testing.

4. Additional research is needed in the area of display enhancement, either of the edge or detail sharpening kind, or of multi-spectral or multi-sensor analysis. The effects of gamma alteration and of optical filtering need further work.

5. Work is needed on the interactive effect of contrast (display), signal to noise ratio and shades of gray.

6. The interactive effect of horizontal and vertical resolution should be investigated. A study of this nature should also investigate further the effects of raster orientation, display aspect ratio, bandwidth, and limiting resolution.

7. The effects of target angular subtense with resolution, scene complexity, both display and target contrast, and signal to noise, and ambient illumination, should be determined.

8. The interaction of display size, viewing distance, and display resolution needs further work.

9. The effects of sensor FOV on TA and its interaction with mission parameters and task requirements need additional research to determine optimum values.

10. Studies to determine the interaction among number of TV lines subtending the target, system spot size, resolution, target angular subtense, signal to noise ratio and search time are also needed.

11. The interaction of frame rate with bandwidth and other scanning system parameters needs to be investigated further.

12. The effects of scene clutter on the search time requirements should be determined when scanning a dynamic display.

13. The effects of visibility conditions on displayed contrast should also be determined and hence its effects on TA performance.

14. The effect of rate of image motion on the display on TA needs to be determined more accurately with regard to task variables and mission and display conditions.

15. Additional research on the effects of display freeze on TA performance would be desirable.

16. Helmet-mounted and heads-up displays for TA cueing should be investigated.

17. The efficacy of zoom optics over fixed-optics should be further investigated.

18. The effect of briefing aids and techniques on TA needs to be further investigated along with the effect of training level of observer when using the display.

19. The effect of sensor search pattern on TA needs to be determined. In the case where the sensor is forward-looking, the effect of down-look angle on TA needs to be determined.

20. New types of displays such as plasma, charge-coupled devices, etc., need to be developed and tested for application to the TA problem(s).

21. The effect of observer variables on TA needs to be explored. This research would determine whether the use of displays is dependent upon visual search, training, and/or visual capability. Individual differences as determined by tests such as the Embedded Figures Test, form discrimination tests, etc., would be correlated with scores on TA tests in a simulator or from photographic protocols as they relate to real time, dynamic displays used in target acquisition.

7.2.5 Observer Parameters

7.2.5.1 Design Recommendations

1. Where possible, locate prospective targets in the center of the observers' natural field of view, at or near the center of display or viewing area. Targets more than a few degrees off the axis of vision will not be rapidly acquired unless they are cued in some manner.

2. Only targets inside a practical two degree cone of foveal vision will be reliably, rapidly acquired.

3. Recognize that the observer fixates on a spot from 0.2 to over 1 second, with a modal value of 0.33 second. Effective detection requires at least that long if the observer is looking directly at the point. Actual acquisition time is much longer (see 4. below).

4. Design the system to allow adequate search time. Modal search time to find a target in a pre-briefed area is about 25 seconds; targets not found after 45 seconds search will probably not be found.

5. "Training" will not necessarily make a poor system work. Trained, experienced observers are not always better at finding targets rapidly; they are, however, less variable.

6. Limit the additional tasks required of an observer while he is searching. The observer should search for and acquire targets with as little else to do as practical.

7. Provide cueing aids as an integral part of the target acquisition system. Cueing devices significantly improve target acquisition capability, either by direct vision or when searching a display.

7.2.5.2 Operational Implications

1. Select as observers those individuals who have the best measured peripheral acuity.

2. Train observers to search in a methodical, standard pattern.

a. For detection: if the aircraft design allows it, focus on the far horizon, slowly search back along the line of flight, then focus ahead on the horizon and repeat.

b. For recognition: when a suspected target is detected concentrate foveal vision on the area and its surrounding context. Several seconds of concentrated search about an area are worth minutes of random search patterns.

3. Provide observers with as much specific experience about an area as possible. In most cases knowledge about an area is at least as important as generalized target acquisition training.

4. Train observers in how to search and in what to search for. Geographic areas of the world have different "target-background complex" relationships. Specific knowledge about the area of operations significantly improves target acquisition performance.

5. "Good" navigation to the target area makes for "good" target acquisition. Train observers in effective navigation as well as finding targets.

6. Whenever possible use as observers those who want to be observers and who believe that they are good at it.

7. When searching for and acquiring targets the observer should have no other task. Target acquisition is a full time job.

8. The one most important thing that will help assure target acquisition is effective prebriefing about the target and the target area complex. The more briefing materials simulate the actual target approach, the better will be the target acquisition.

   a. Plan approach routes to give maximum view of the target.

   b. Provide oblique photographs or sketches that "view" the target and target area complex from the same angles as the planned approach route.

   c. Require thorough map and/or photograph study before each flight.

   d. Tell the observer "what to look for" in as much detail as possible. Contrast, size, shape and context of the target in its background are important.

   e. Provide information about the overall target area as well. Knowing where to look is as important as knowing what to look for.

   f. Provide information on when to look.

8. Provide enough time to look. Even if the observer knows what, when, and where the target is located, experimental data show an average of 20 to 40 seconds is needed to find a target from the time first possible to acquire it.

9. Use any possible cueing and/or navigation aids provided by the system.

7.2.5.3 Research Required

1. What is the relationship between eye fixation and operational target acquisition? What normal patterns of eye fixation are related to those who are effective at acquiring targets? Can eye fixation patterns or rates be used as a selection method for observers?

2. Is peripheral visual acuity important in operational target acquisition?

3. What characterizes the most effective target acquisition search strategies?

4. What are the best training methods for target acquisition? Can effective patterns of search be taught and retained?

5. How can observers be motivated to perform well, and personally feel a sense of competence at the task?

6. Are there any personal differences between observers that can be reliably evaluated and used as prospective selection devices?

7. When does operationally relevant task loading begin to interfere with target acquisition performance? What types of operational tasks are competitive with target acquisition?

8. What natural cues should be emphasized in preparing pre-briefing materials?

9. How effective are artificial cueing aids? What types of cueing are best? What, and how, should cueing data be presented to the operator?

10. How does knowledge of the terrain and the target area affect the probability of target acquisition?

11. Is the concept of modulation transfer function of the human visual system a viable one for predicting and modeling target acquisition performance? In the direct visual case? When observing real-time type displays?

12. Can signal detection/decision theory concepts be effectively applied to target acquisition models and tasks?

7.3 Access to the Literature

The bibliography of this source book represents the large majority of the relevant work in air-to-ground target acquisition. As a convenience and as a guide to those who may wish further, more detailed information, Appendix A contains a set of tables which provide a means of entry to the data represented in the bibliography. Listed by reference number in the tables are key studies, reports, and theoretical papers concerned with the parameters noted as being involved in target acquisition. The general outline of topics as shown in Figure 1-2 was used in preparing the tables. While not all references cited in the bibliography are listed in the tables, they do contain those reports that the authors consider most pertinent.

7.4 Typical Target Acquisition Results

The following figures and tables are an attempt to summarize typical target acquisition data. These charts must be viewed with caution. They represent considerable "smoothing" of the data. They are best estimates and in many cases the bases for them are not stated. They are often summaries of summary data as presented in experimental and field test reports. (The problems of field test results and the dubious value of the data therefrom have previously been noted.) Finally, effects of altitude and speed and criteria of acquisition are not usually included. These are "best" data.

Figure 7-1 is taken primarily from the summary of field test data by Bliss (1965) and was originally used in developing technical evaluation criteria for the Walleye weapons system. Recently unclassified, it is of historical as well as technical interest. Note that the plotted general distribution of target acquisition ranges shown thereon does not exactly correspond to the Gaussian normal distribution usually assembled in most mathematical models. Is a change in modeling concepts indicated?

Figure 7-2 is developed from unclassified data contained in reports of field tests conducted since 1963. This figure is plotted to the same scale used in Figure 7-1. All data are for flight altitudes above 1500 feet. A comparison of the two is interesting. Where available from the data, "recognition" was the criterion.

Table 7-I shows typical visual target acquisition ranges for several targets as reported using simulators, both terrain model and motion picture. Compare these with the data shown in the previous figures.

7.5 Concluding Note

Recently a colleague reached the following conclusion: "After reading all about target acquisition I have decided that the only sure way to acquire a target is to buy it." We need not be that pessimistic. But effective target acquisition does require much work and more than a little luck. Understanding of the problem is taking a long, slow, hard effort on the part of many people in many disciplines. No big breakthrough is on the horizon nor should one be expected.

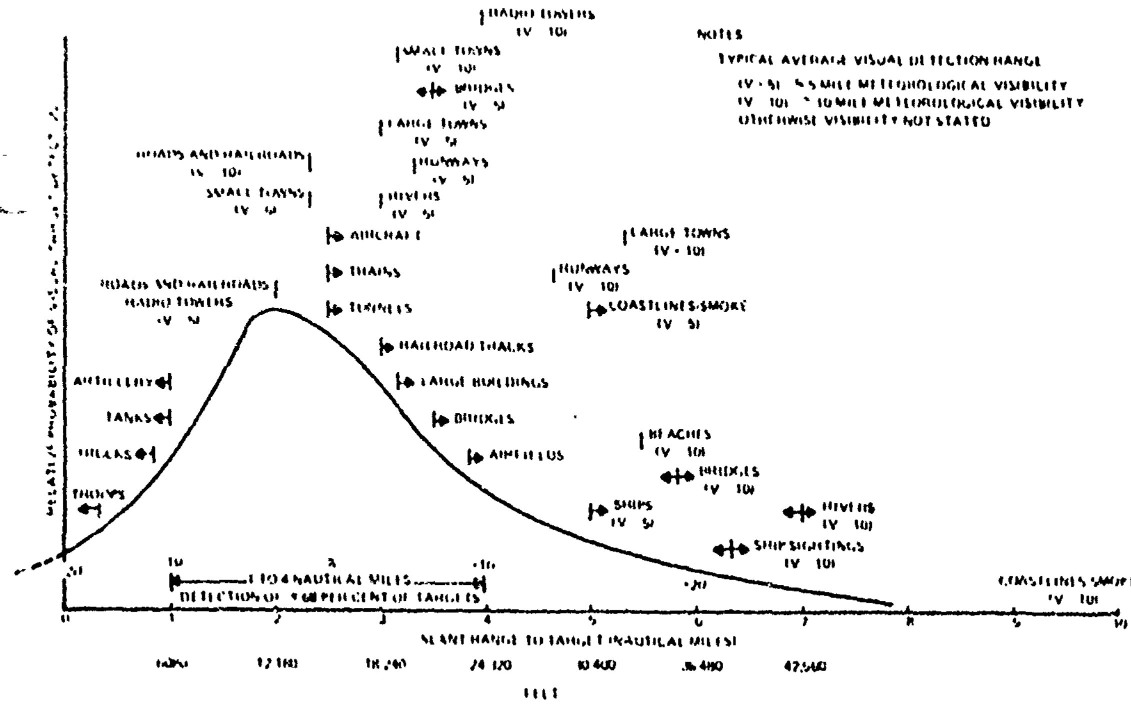


Figure 7-1. Average Visual Detection Range Based on Analysis of Test Data. (1965)

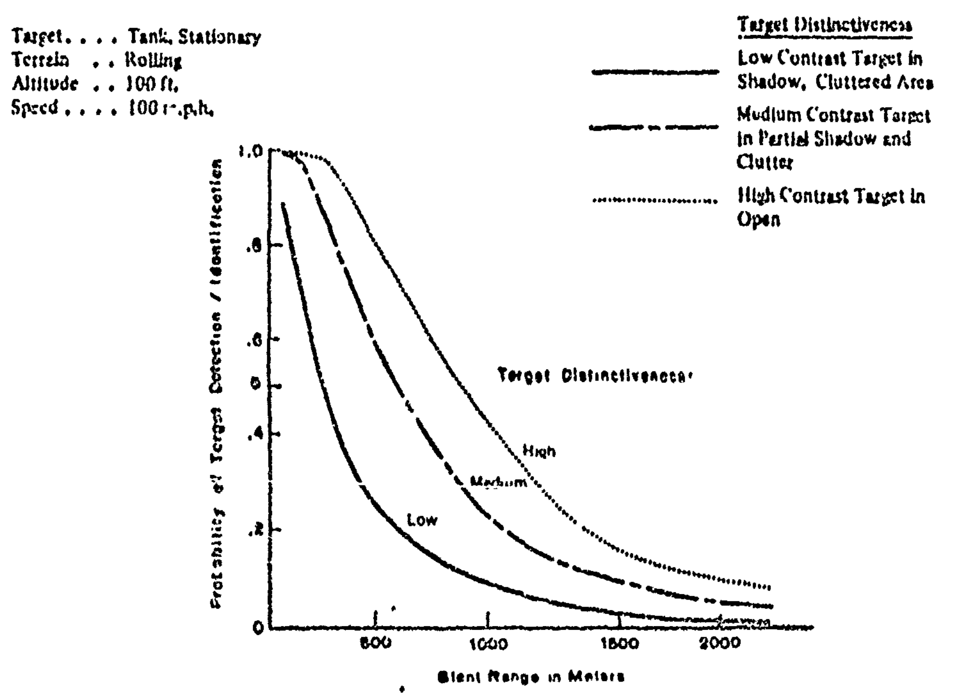


Figure 7-2. Helicopter Observer Field Test Data Compared with Franklin and Whittenburg Model Prediction. Source: HEL TN5-74

TABLE 7-1

Comparison of "Typical" 50 Percent Probability Target Acquisition by Three Methods

	Typical Field Tests Visibility				Typical Terrain Model Simulator		Typical Motion Picture Simulator	
	5 miles feet	(8 km) meters	10 miles feet	(16 km) meters	feet	meters	feet	meters
Single Tank	4,500	1,370	6,500	1,980	7,000	2,135		
Radar Van*			7,850	2,390			4,100	1,250
Three Vehicles	13,730	4,200	13,970	4,250	15,000	4,570		
SAM Launcher			15,200	4,630	13,550	4,130		
AA Gun Emplacement			1[illegible],400	3,780	13,350	4,070		
SAM Emplacement			13,800	4,210	16,200	4,950	5,000*	1,525
House			19,450				6,700	2,200
Large Building					22,000	6,700	16,000	4,875
Watch Tower			12,000	5,930			8,200	2,500
Rail-River Bridge			22,000	6,700	26,500	8,070		
"Large" Bridge							7,000	2,135
Cross Road			13,376	4,070	15,250	4,650	5,800	1,910
Airport Runway	16,000	4,875			18,0[illegible]	5,490	10,000	3,048
"Ships"	22,000	6,700	40,700	12,400			19,000	5,790
	Altitude: 2000-5000 feet (610-1524 meters)				Speed 175-500 knots (324-927 km/hr)		*900 ft (274 m) altitude	

7.6 Example of a Good Technical Paper

In the course of the wide-ranging literature search which was conducted preparatory to assembling this source book, the authors reviewed papers of a quality ranging all the way from technically invalid and poorly written, to those which are or are destined to become standard TA references.

One paper was found which is direct, concise and a good example of a straightforward presentation of data. Since it is relatively brief, it was decided to reproduce the paper in its entirety, in the hope that it may serve as a model to follow in the reporting of study and experimental results.

This paper, entitled, "The Form of Visual Detection Data," first appeared as a working paper of the Target Acquisition Working Group of the Joint Technical Coordinating Group for Munitions Effectiveness. The principal investigator and preparer of the paper is Ronald A. Erickson, Naval Weapons Center, China Lake, California. The paper is to be published as a NWC technical publication in the near future; it is reproduced here with Mr. Erickson's permission.

THE FORM OF VISUAL DETECTION DATA

By

Ronald A. Erickson
Naval Weapons Center
China Lake, California

A Working Paper of the
TARGET ACQUISITION WORKING GROUP
JTCG/ME JMEM/AS

10 August 1972

THE FORM OF VISUAL DETECTION DATA

INTRODUCTION

This working paper discusses some concepts of the description of visual detection performance by aircrewmen. The methods of performance, and the accuracy in describing this performance are discussed and related to the analysis required for weapon system specification. The sighting of an aircraft has been used as an example in the discussion.

FORMS OF TARGET ACQUISITION DATA

MEASURES

The measures used to describe visual detection performance in airborne situations are (a) range and angular coordinates of the target at detection, and (b) probability of detection. The basic data can be generated experimentally by exactly repeating a given situation a number of times (same pilot and same environment). A distribution of the pilot's reports can be drawn (Fig. 1) and plotted cumulatively (Fig. 2).

The ranges shown in Fig. 1 may be detection, recognition, or identification range. These words are best defined by a description of the briefing given to the pilot. Example definitions follow:

At detection--The pilot reports that he sees an object in the air which is not a meteorological phenomenon (e.g., clouds).

At recognition--The pilot reports that the object is a fixed-wing aircraft.

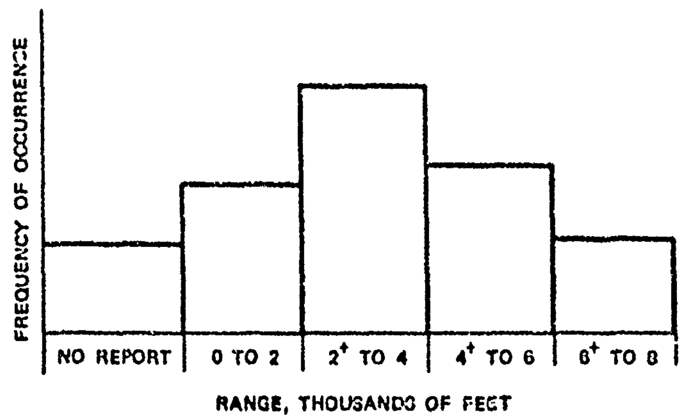


FIG. 1. Distribution of the Range at Which an Aircraft is Sighted for a Specific Environmental Situation.

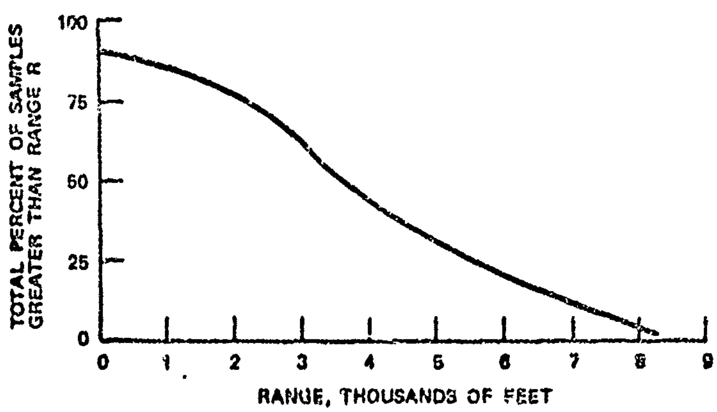


FIG. 2. Normalized Cumulative Plot of the Distribution in Sighting Ranges Shown in Fig. 1. This figure is usually called the cumulative percentage of detection range.

At first identification level--The pilot reports that the aircraft is a small jet.

At second identification level--The pilot reports that the aircraft is an F-4.

The perceptions associated with these different kinds of reports may be separated in time, in range, or they may occur simultaneously. When the report is made, some level of confidence is associated with it. This level of confidence can be manipulated to some extent by the briefing or by informal competition among subjects.

LABORATORY DATA

Analysts frequently use laboratory data as a basis for extrapolation to the real world. Few of them really take a hard look at the conditions under which the data were collected. A comparison of the conditions in the laboratory and in the real world is necessary, however, to aid in assessing the applicability of the laboratory data to the real world.

Laboratory data of possible application to the modeling of the aircraft sighting process have been collected with (1) no visual search required (and the target presented both on and off the point of fixation), (2) visual search in an empty field, and (3) visual search in a structured, or cluttered field. Most of these experiments use a time limit and/or a forced choice procedure. In forced choice, the subjects must give an answer as to where (e.g., which sector) or when (e.g., which time interval) the target was presented. In most of these tests, abstention is not allowed; that is, "I don't know" or "I didn't see anything" are not in the choices. If the subjects are not sure, they must guess at an answer.

Experimenters prefer forced choice because the data have less variability. Such data can be summarized in the format shown in Fig. 3. Only five discrete sizes were tested in this hypothetical experiment; it would usually be assumed that performance varies *continuously* with target size, however.

In this hypothetical experiment, each target size was presented the same number of times to a number of observers. It is seen that every time a target subtending 12 min of arc was presented, its location was correctly reported. Ten percent of the 4 min of arc target locations were correctly reported.

If forced choice is used in the expe imen , the subjects will get some answers right regardless of whether or not the target is *perceived*. To take this into account, the scores for guessing are sometimes corrected by the equation,

$$S = \% \text{ Right} - \frac{\% \text{ Wrong}}{N - 1} \qquad (1)$$

where

S = % right, corrected for guessing

N = number of alternatives (choices) the subject has in responding.

It should be pointed out that this correction for guessing may have no significance or may not fit the assumptions behind some mathematical models (Harris, 1963).

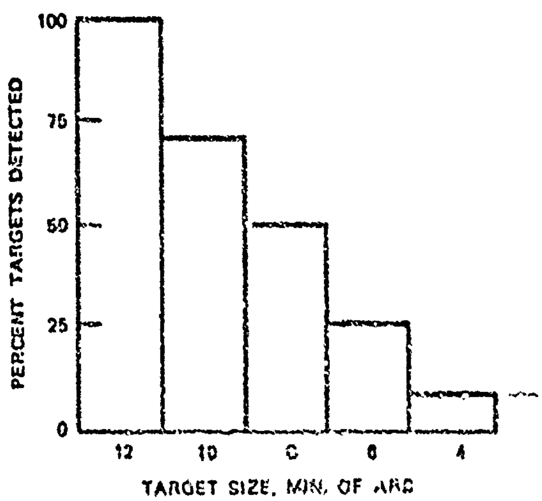


FIG. 3. Data Format for Detection of Targets of Variable Size (With All Other Characteristics Held Constant).

The data in Fig. 3 can be corrected for guessing if it is assumed that there are ten equally difficult alternatives for each response (Fig. 4). If it is assumed that the response process is *continuous* with target size, the data also can be smoothed (Fig. 5).

Figure 5 appears to be similar to Fig. 2, with total percent of samples equivalent to percent targets detected, and range corresponding to target size. These curves are *not* equivalent, however; the key reason is that Fig. 2 is derived from a free search, no-time-limit, call-it-when-you-see-it type situation. *All* the sightings are voluntarily reported with an unknown, but probably high, confidence level. The data in Fig. 5 are forced choice in a restrictive situation; the percent targets detected probably correspond to the confidence level (which is variable down to zero).

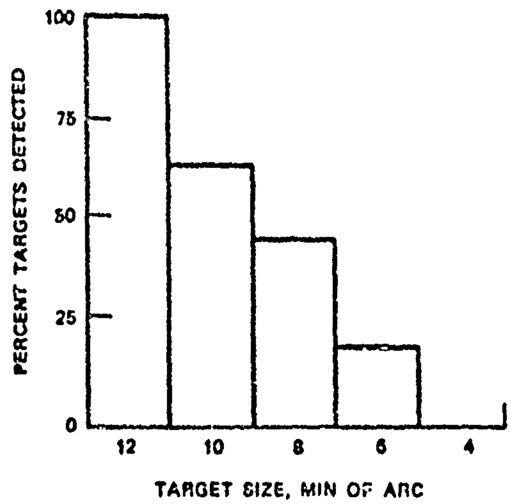


FIG. 4. Data Shown in Fig. 3 Corrected for Guessing (Assumed Chance Level = 10%).

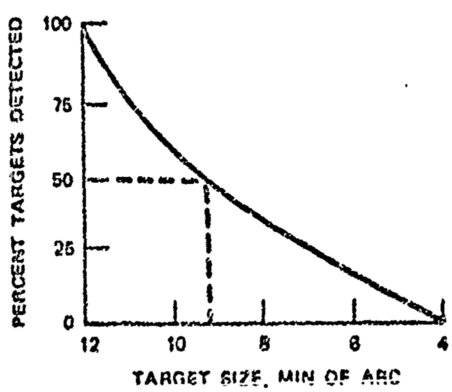


FIG. 5. Percent Targets Detected as a Function of Target Size, and Corrected for Guessing Assuming Continuous Function.

The curve in Fig. 5 represents performance under one set of conditions for targets of different sizes. A large number of such curves are produced in an experiment where several parameters are varied. These are usually summarized by picking one point off of each curve (the dotted line in Fig. 5) to use as an indicator of performance. The rationale for this is given in (Taylor, 1964).

> "It is found, upon plotting many hundreds of such stimulus presentations, that the probability of target detection rises with stimulus magnitude in accordance with an ogive curve which is well fitted by a normal Gaussian integral. Statistically, the best determined point of the ogive is the point of inflection, i.e., where the probability of correct discrimination is 0.50, and this is the value of threshold contrast of prime interest in laboratory studies."

An example of such summary data (which is usually the only data that is published) is shown in Fig. 6 (Blackwell, 1969).

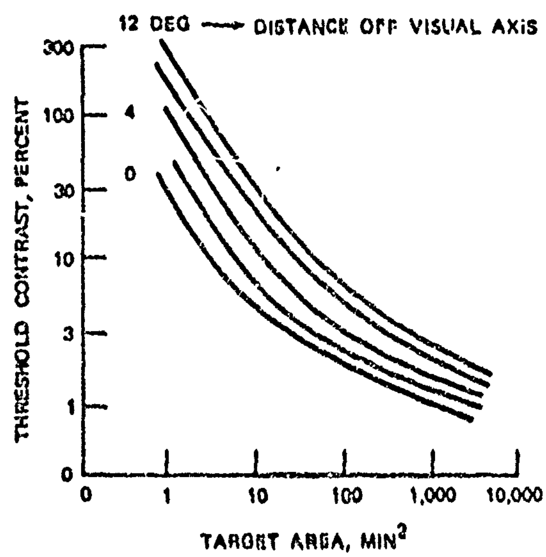


FIG. 6. Threshold Contrast for Circular Targets Against a Background Luminance of 75 Foot-Lamberts With a 1/3-Second Viewing Time.

USING LABORATORY DATA IN A MODEL OF THE REAL WORLD

There are many differences between th[illegible] [illegible]tory test conditions and those usually encountered in operati[illegible] [illegible] [illegible]t. Application

of such laboratory data to mathematical models of field situations can produce erroneous results for at least two reasons:

1. The accuracy of the model's description of the visual search process is not known. Assumptions are usually made (e.g., type of scan pattern), which are pure speculation.

2. The situation in which the laboratory data were collected usually is not at all similar to the situation being modeled.

The first inadequacy can be improved by collecting flight data (e.g., photographs of the pilot) to better describe the process. Performance data can also be collected during such tests. The second inadequacy is *corrected* empirically by applying fudge factors to the laboratory data. An example of the process is taken from Taylor's discussion (IBID).

> "At this point, it is well to give an example of how a field factor is determined for a real case, and how it may be used to arrive at a realistic estimate of observer performance under field conditions. Let it be assumed that an observer must confidently detect the occurrence of a stimulus of known duration and size but of unknown location within a circular display area with a diameter of 8°. The target will be present at infrequent intervals, say once every 15 min or so, and he can be allowed to miss only 5% of the occurrences. He is new to the task, and our problem is to arrange the contrast of the target so that this 95% criterion will be met. We begin by consulting the laboratory data, which tell us that, for our target size and duration and for the prevailing adapting luminance, the required contrast for 50% correct discrimination by practiced observers in a forced-choice experiment was found to be 0.0061. To correct, respectively, for confidence level, unknown location, vigilance, and lack of training we multiply this contrast value by 1.64, 1.31, 1.19, and 2.00, i.e., by 5.12. The needed target contrast, therefore, is 0.031 for our problem.
>
> "It should be noted that this estimate refers to the 0.95 confidence level in forced-choice terms. An additional factor of 1.2 in contrast may be used to approximate ordinary seeing. It is often necessary to use laboratory threshold data from 'yes-no' experiments; in this case, a rough rule of thumb is sometimes used which calls for doubling the liminal contrast value.

"Additional contributions to the field factor may occasionally occur. These tend to be even more highly individual, and generally derive from specific environmental conditions and observer states, e.g., oxygen deprivation, dietary factors, acceleration, vibration, fatigue, distraction, toxic atmosphere, glare, anxiety, sensory deprivation, abnormal thermal levels, and a host of others. Only fragmentary data can be adduced in most cases, and it is commonly found necessary to assess these effects by means of specific experiments."

An error analysis performed as part of the development of a mathematical model of the visual detection process is rare. The discussion by Taylor quoted previously gives some indication of how many sources of error are just in the *field factor.*

THE TOTAL PICTURE

It is useful to derive a model, or concept of how *all* air-to-air sightings can be described. The whole world, or as the staticians say, the "total population" consists of the results from all the actual encounters. Of course, these results are not known since (a) as they occur, the data are not recorded properly; and (b) those of interest are in the future. This total population can be *estimated* with a mathematical model, a laboratory simulation, and/or flight test simulations. The accuracy of such an estimate will directly affect the validity of the analysis leading to weapon system specification.

The basic data describing performance are shown in Fig. 1. The reason for the spread in the reported ranges for the same pilot and the same environment has been attributed to variation of the pilot's characteristics (motivation, alertness, and sensitivity) from time to time, and to the existence of a random component in the visual search process. The spread is commonly found in experiments and is also found in decision theory models.

Performance differences between pilots will result in a range of performance curves similar to Fig. 2 for each situation (Fig. 7). These curves can be combined across pilots to give a summary measure of performance *for a given set* of environmental conditions (Fig. 7).

The total population of performances (Fig. 8) might be described by a number of the types of curves shown in Fig. 7. Any one curve describes performance for a particular set of environmental conditions, or for a number of sets of conditions; e.g., performance against a large, low-contrast target may be the same as that against a smaller, higher-contrast target. The boundary curves in Fig. 8 are tied to the real world by the following two statements:

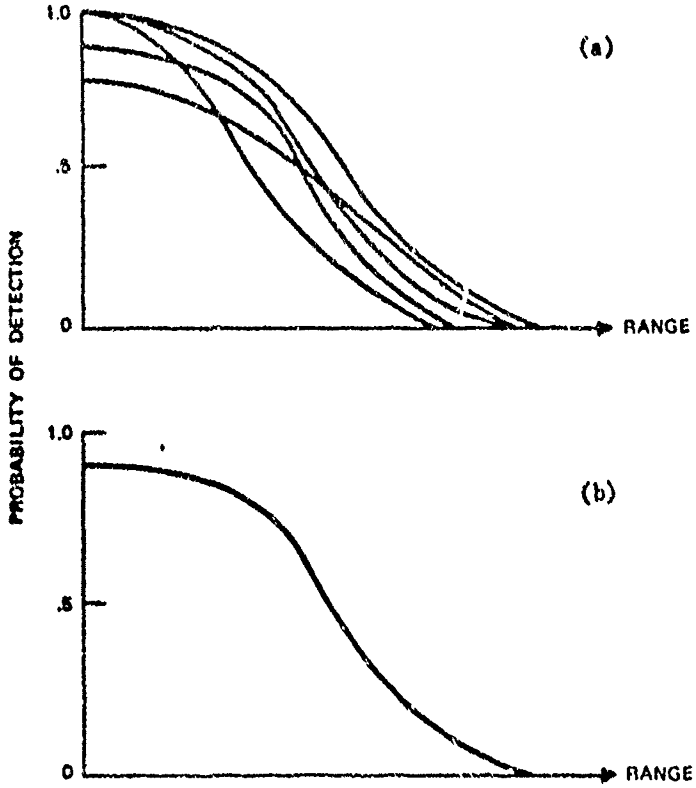


FIG. 7. (a) Performance Curves for Individual Pilots, and (b) Summary Performance Curve for the Group for a Given Situation.

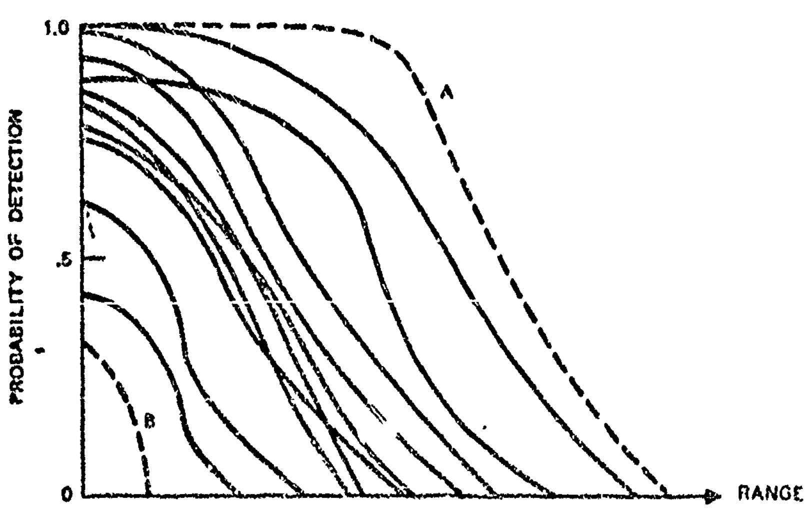


FIG. 8. Total Population of Performances.

Curve A might be detection of a large, high-contrast target in a clear atmosphere when the pilot knows when and where to look.

Curve B might be detection of a small, low-contrast target when the pilot's expectation of an encounter is low, and the target can appear anywhere.

PROBABILITY OF OCCURRENCE

Establi' 'nt of all the probable sets of environmental conditions and de· ·ion of the performance curve for each have still not adequately de. ed the total population. The probability of occurrence of each curve is also required. A three-dimensional plot of Fig. 8 with the probability of occurrence added as the third dimension is shown in Fig. 9. (Figure 8 is shown in the horizontal plane of Fig. 9.)

Figure 8 illustrates that the performance curves are not expected to occur with a uniform density in the P_D/R plane. Hence, Fig. 9 may be considered to be a solid, but one whose density (number of performance curves per unit $P_D \times R$ area) is variable.

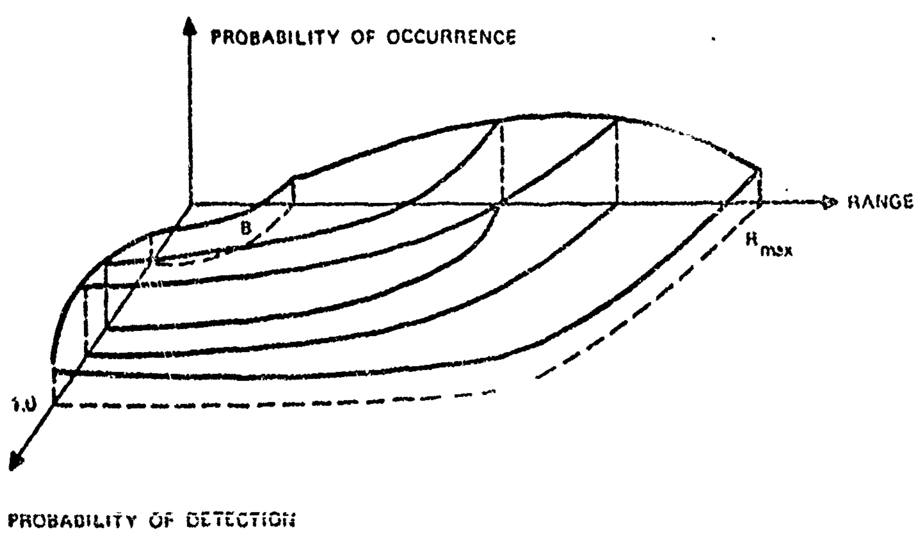


FIG. 9. Probability of Occurrence/Probability of Detection as a Function of Range.

PERFORMANCE OF THE TOTAL POPULATION

The integral of the solid shown in Fig. 9 (wi' nsity included as a fourth variable) can be normalized to a *mass* of on describe the total population of encounters where detection occurred (Eq. 2).

$$D_{total} = \int_{R_{max}}^{0} P_D \times P_{occ} \times \text{Density} \times dR \qquad (2)$$

The plot of this normalized integral as a function of R shows the percent of all detections (under all conditions to be encountered by all pilots) which can be expected to occur by range R (Fig. 10) where R varies from R_{max} to zero. An analyst could use this plot to select a missile range which would include any percent of expected encounters he desired.

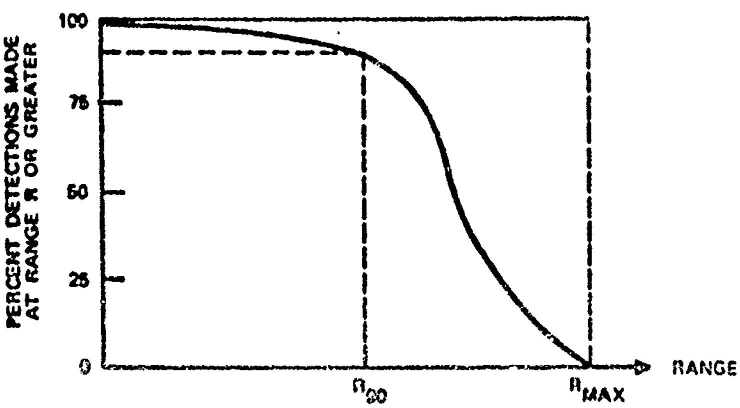


FIG. 10. Cumulative Detections.

APPENDIX A

SUMMARY OF TARGET ACQUISITION LITERATURE

While conducting this survey of the target acquisition field, a very large number of references were found, reviewed, and assembled into the bibliography which follows. The resultant listing is so extensive (more than 1750 entries) that summary tables are presented for quick reference purposes. The results, which are similar to previous efforts by Franklin and Whittenburg (1965), Parkes (1972), Lloyd (1973), and Price (1974), are presented in Tables A-I through A-VI.

These tables contain relevant references classified by the more important variables in air-to-ground target acquisition, and furnish key entry points into the target acquisition literature. As such they can be used as a tool with which users can readily find sources of data on characteristics and variables of particular interest.

An attempt was made to present a representative collection of references on the listed variebles. It is entirely possible that in the effort to keep the tables at a manageable and useful size, some important documents were not included. Nevertheless, it is beieved that the tables are more than adequate as a ready reference file backed up as they are by the comprehensive bibliography.

To find an appropriate reference, first look for the table which contains the general subject title, e.g., Table A-I Target/Background Parameters. Opposite the parameters appropriate to the subject are listed a series of numbers, which are identifiers of items in the bibliography. Using this short cut, a representative group of references for a particular subject can be readily identified and ordered from the usual sources (DDC or as indicated in the entries).

TABLE A-I

Target/Background Parameters

Type	52, 271, 1732
Size	76, 119, 120, 157, 162, 167, 178, 184, 324, 392, 514, 565, 703, 747, 786, 821, 874, 921, 9[illegible]5, 937, 965, 966, 1059, 1094, 1152, 1163, 1190, 1244, 1245, 1376, 1428, 1460, 1478, 1487, 1491, 1525, 1526, 1529, 1565, 1576, 1614, 1672, 1739
Shape	152, 157, 162, 167, 201, 203, 313, 326, 343, 365, 369, 402, 415, 561, 703, 779, 921, 931, 933, 935, 956, 957, 965, 966, 1059, 1136, 1190, 1198, 1208, 1209, 1242, 1270, 1301, 1324, 1328, 1331, 1425, 1433, 1470, 1471, 1472, 1473, 1480, 1487, 1491, 1525, 1547, 1565, 1587, 1609, 1630, 1637, 1631, 1664, 1701, 1727, 1748
Contrast	142, 151, 153, 156, 184, 200, 209, 318, 322, 336, 388, 505, 556, 559, 565, 768, 874, 965, 966, 102[illegible], 1115, 1137, 1163, 1296, 1324, 1346, 1428, 1478, 1624, 1636, 1644, 1662, 1739
Color	76, 116, 246, 262, 310, 339, 527, 579, 592, 599, 637, 645, 646, 679, 750, 764, 768, 779, 870, 878, 931, 1096, 1115, 1139, 1161, 1189, 1292, 1328, 1352, 1372, 1415, 1426, 1447, 1448, 1454, 1482, 1523, 1529, 1541, 1342, 1624, 1643, 1679, 1736
Luminance/Reflectance	162, 167, 185, 186, 187, 189, 246, 318, 439, 457, 509, 557, 582, 630, 631, 690, 709, 901, 954, 997, 1073, 1292, 1328, 1487, 1491, 1529, 1586
Texture	559, 868, 884, 1299, 1331, 1426, 1489

Motion	60, 125, 123, 196, 242, 243, 251, 358, 359, 360, 361, 366, 414, 419, 420, 421, 431, 440, 479, 480, 482, 500, 504, 505, 517, 603, 604, 617, 650, 755, 776, 786, 950, 996, 997, 998, 1009, 1043, 1052, 1056, 1111, 1143, 1146, 1152, 1153, 1195, 1207, 1296, 1466, 1628, 1639, 1648, 1650, 1651, 1652, 1667, 1742
Shadow	570, 623, 868
Terrain Type	79, 81, 147, 499, 505, 556, 1282, 1291, 1344, 1379, 1423, 1624, 1669, 1732, 1734
Vegetation	398
Masking	177, 178, 297, 424, 499, 500, 505, 650, 655, 1516, 1718
Counter Surveillance (Camouflage)	444, 484, 485, 644, 665, 673, 948, 1197, 1287, 1449, 1508, 1653
Clutter	29, 61, 64, 146, 177, 179, 184, 199, 221, 240, 265, 317, 505, 685, 767, 819, 964, 1017, 1124, 1152, 1236, 1335, 1488, 1525, 1526, 1624, 1662, 1739
Cues	184, 266, 557, 571, 577, 1001, 1062, 1105, 1106, 1107, 1108, 1109, 1373, 1605
Distinctiveness	146, 199, 201, 202, 267
Conspicuity	177, 184, 486, 801, 1703, 1704, 1705, 1706, 1707, 1708
Embeddedness	178, 179, 184, 938, 1739
Ambiguity	152, 751, 1169
Confusability	152, 294, 426

TABLE A-II

Aircraft Parameters

Altitude	49, 60, 78, 81, 170, 206, 321, 610, 632, 655, 694, 712, 726, 732, 734, 762, 803, 877, 917, 1068, 1102, 1148, 1149, 1230, 1231, 1326, 1416, 1456, 1468, 1495, 1504, 1506, 1515, 1516, 1517, 1518, 1588, 1591, 1593, 1596, 1646, 1669, 1702, 1715, 1724, 1732, 1740
Range	94, 173, 174, 172, 610, 618, 917, 1230
Speed	52, 206, 268, 269, 271, 438, 460, 461, 726, 877, 880, 917, 1074, 1113, 1148, 1231, 1326, 1373, 1416, 1431, 1456, 1515, 1517, 1518, 1534, 1588, 1669, 1733, 1740
Offset	505, 572, 650, 1160, 1732
Target Exposure Time	50, 173, 174, 177, 204, 303, 500, 1592
Type Aircraft	92, 227, 229, 410, 424, 434, 662, 694, 850, 854, 860, 915, 1033, 1165, 1168, 1284, 1455, 1494, 1577, 1578, 1728
Seat Position	49, 92, 424, 734, 914, 1156, 1307
Apparent Motion	50, 98, 149, 147, 231, 233, 234, 241, 289, 325, 340, 438, 500, 505, 650, 876, 1071, 1133, 1172, 1176, 1253, 1354, 1505, 1523, 1618, 1708

TABLE A-III

Environment Parameters

Visibility	89, 103, 108, 146, 160, [illegible]66, 185, 186, 187, 188, 197, 207, 244, 276, 321 329, 330, 371, 418, 436, 443, 444, 446, 447, 449, 457, 458, 528, 536, 548, 585, 586, 614, 625, 628, [illegible]81, 686, 748, 937, 945, 1019, 1047, 1048, 1083, 1116, 1141, 1142, 1197, 1214, 1293, 1298, [illegible], 1337, 1344, 1348, 1369, 1571, 1573, 1574, [illegible], 1619, 1636, 1638, 1649, 1660, 1665
Cloud Cover	531, 1013, 1117, 1410, 1617, 1612, 1623, 1723
Sky-Ground Ratio	189, 454, 477, 625, 626, 630, 1141, 1322
Sun Angle	187, 570, 623, 868, 1426, 1662
Illumination Level	86, 91, 96, 98, 99, 128, 134, 153, 161, 182, 255, 288, 395, 538, 553, 642, 740, 824, 825, 893, 901, 936, 1044, 1046, 1135, 1145, 1155, 1199, 1292, 1308, 1469, 1574, 1671
Diurnal Variation	423, 456, 1492, 1612, 1623
Seasonal Variation	306, 307, 308, 309, 531, 1014, 1344, 1492, 1612, 1617, 1623, 1723, 1726
Scintillation	111, 112, 331, 505
Glare	406, 466, 540, 716, 1317, 1528, 1627, 1717
Attenuation	58, 147, 185, 186, 187, 189, 219, 296, 327, 373, 477, 482, 483, 524, 1095, 1097, 1142, 1141, 1329, 1563, 1604, 1627, 1726
Transmittance	58, 147, 185, 186, 187, 189, 250, 372, 437, 445, 476, 477, 540, 796, 970, 1116, 1132, 1320, 1322, 1545, 1575, 1665, 1726, 1729, 1737
Apparent Contrast	185, 186, 187, 188, 189, 147, 219, 327, 437, 445, 446, 451, 453, 457, 625, 1141, 1142, 1317, 1322, 1329
MTF	85, 86, 114, 115, 129, 131, 132, 135, 161, 194, 147, 215, 230, 252, 253, 279, 301, 332, 347, 349, 470, 532, 647, 669, 811, 840, 841, 870, 887, 968, 969

TABLE A-IV

Sensor/Display Parameters

Sensor Type	137, 140, 143, 147, 172, 183, 198, 250, 257, 260, 278, 290, 352, 387, 401, 412, 476, 539, 563, 569, 621, 657, 658, 660, 676, 714, 717, 809, 827, 835, 866, 896, 959, 962, 999, 1027, 1112, 1113, 1177, 1199, 1203, 1238, 1290, 1318, 1322, 1325, 1336, 1345, 1349, 1363, 1381, 1382, 1384, 1461, 1388, 1391, 1392, 1393, 1394, 1411, 1432, 1436, 1437, 1451, 1466, 1628, 1749, 1532, 1553, 1474, 1475, 1496, 1510, 1511, 1512, 1522, 1561, 1528, 1531, 1589, 1613, 1666, 1678, 1694, 1719, 1744
Field of View	103, 137, 195, 459, 508, 571, 635, 559, 813, 953, 979, 1034, 1085, 1093, 1134, 1225, 1234, 1237, 1268, 1375, 1376, 1467, 1537, 1597, 1660, 1668, 1700, 1701, 1702, 1733, 1735
Resolution (and Raster Line #)	63, 111, 112, 137, 139, 175, 212, 213, 267, 285, 334, 433, 478, 516, 517, 518, 519, 693,696, 700, 707, 834, 848, 849, 902, 930, 978, 979, 1002, 1007, 1008, 1019, 1028, 1057, 1085, 1192, 1195, 1234, 1239, 1240, 1241, 1285, 1395, 1404, 1405, 1406, 1421, 1420, 1444, 1457, 1458, 1459, 1460, 1486, 1490, 1673, 1683, 1700
Contrast Ratio	16, 68, 247, 248, 334, 464, 608, 607, 559, 1269, 1413, 1459
Gamma	17, 555, 542, 1093, 1119, 1407, 1450
Signal-to-Noise	17, 131, 135, 137, 175, 210, 211, 333, 788, 1130, 1234, 1435, 1700
Frame Rate	17, 62, 127, 432, 462, 49[illegible], 590, 813, 1057, 1119, 1178, 1234, 1407, 1420, 1430, 1450
Interlace	17, 62, 127, 813, 1057, 1119, 1407, 1450
Integration Time	62, 1346, 1420

Pointing Angle (Viewing)	1460, 1712
Display Size	68, 126, 251, 363, 370, 490, 494, 514, 643, 1073, 1075, 1099, 1119, 1157, 1170, 1216, 1434, 1483, 1683, 1711
Aspect Ratio	663, 773, 1434
Viewing Distance	17, 68, 176, 247, 248, 251, 1075, 1099, 1119, 1170, 1278, 1434, 1455
Displayed Signal-to-Noise	16, 131, 132, 135, 137, 194, 348, 368, 506, 515, 520, 574, 591, 600, 804, 1008, 1066, 1193, 1279, 1355, 1356, 1357, 1358, 1359, 1360, 1361, 1412, 1413, 1599
Color Spot	116
Wobble	135, 136, 131, 1599
Scene Rotation	319, 572, 1315, 1521
Display Freeze	1178, 1371, 1377, 1378
Enhancement	37, 100, 132, 165, 212, 214, 303, 356, 465, 493, 576, 679, 715, 808, 1006, 1038, 1167, 1229, 1371, 1389, 1390, 1448, 1541, 1542, 1625, 1647, 1693
Imagery Quality and Assessment	888, 889, 932, 991, 994, 1007, 1021, 1029, 1045, 1070, 1124, 1147, 1164, 1179, 1189, 1236, 1295, 1364, 1386, 1396, 1397, 1398, 1399, 1402, 1403, 1404, 1413, 1412, 1414, 1419, 1422, 1427, 1445, 1496, 1497, 1498, 1500, 1507, 1514, 1543, 1604, 1696, 1709, 1743

TABLE A-V

Observer Parameters

Fixation	163, 164, 167, 176, 361, 491, 552, 629, 653, 654, 691, 688, 692, 697, 1060, 1061, 1062, 1067, 1365, 1554, 1640, 1676, 1677, 1678, 1706, 1707, 1710, 1738
Search Time	84, 126, 163, 177, 254, 316, 317, 344, 354, 389, 390, 501, 503, 506, 504, 552, 629, 653, 654, 697, 720, 729, 796, 798, 799, 952, 971, 1041, 1173, 1191, 1196, 1235, 1238, 1280, 1467, 1479, 1484, 1485, 1531, 1583, 1584, 1592, 1625, 1662
Search Pattern	9, 83, 150, 169, 177, 190, 302, 310, 355, 376, 405, 422, 491, 492, 507, 552, 583, 601, 605, 626, 629, 634, 654, 699, 710, 826, 919, 942, 943, 1040, 1092, 1100, 1103, 1121, 1173, 1196, 1303, 1304, 1309, 1310, 1311, 1338, 1365, 1439, 1440, 1454, 1461, 1479, 1499, 1594, 1703, 1734, 1738
Visual Acuity	97, 109, 116, 117, 118, 125, 128, 144, 145, 151, 154, 155, 163, 164, 168, 176, 182, 195, 196, 205, 235, 241, 242, 243, 258, 259, 261, 274, 275, 298, 322, 353, 358, 388, 389, 391, 839, 847, 894, 736, 738, 749, 548, 620, 640, 407, 411, 417, 434, 455, 479, 480, 501, 506, 511, 512, 641, 698, 760, 897, 898, 905, 950, 955, 1010, 1024, 1033, 1034, 1042, 1049, 1050, 1052, 1053, 1054, 1055, 1056, 1059, 1091, 1137, 1144, 1145, 1146, 1150, 1151, 1153, 1154, 1155, 1190, 1191, 1193, 1245, 1249, 1300, 1341, 1352, 1414, 1415, 1485, 1505, 1354, 1569, 1570, 1555, 1571, 1573, 1567, 1576, 1578, 1568, 1632, 1633, 1634, 1635, 1644, 1680, 1681, 1725
Experience	156, 364, 507, 958, 1076, 1158, 1159
Training	5, 141, 136, 399, 471, 675, 680, 685, 754, 820, 886, 1054, 1055, 1151, 1204, 1205, 1313, 1424, 1433, 1564, 1572, 1593, 1595, 1645, 1720, 1745
Expectation	8, 156, 324, 922, 929, 1555, 1601

Motivation	1493, 1654
Selection	1429, 1652
Task Load	6, 7, 102, 143, 159, 177, 672, 934, 1231, 1315, 1438, 1462, 1463, 1469, 1518, 1741
Stress and Fatigue	869, 875, 995, 1005, 1188, 1441, 1462, 1463, 1530, 1579, 1580, 1655, 1656, 1657, 1680, 1681, 1697
Number of Observers	190, 521, 794, 1016, 1120, 1186, 1463, 1682
Prebriefing	1, 143, 156, 173, 177, 295, 315, 442, 653, 658, 830, 1112, 1113, 1274, 1275, 1276, 1281, 1283, 1374, 1546, 1597, 1666
Cueing	104, 139, 177, 711, 571, 730, 925, 926, 927, 977, 1270, 1383, 1513, 1595, 1626, 1659, 1745
Search Aids	1, 104, 105, 108, 141, 264, 266, 404, 628, 629, 739, 742, 753, 769, 770, 946, 961, 999, 1065, 1077, 1081, 1108, 1110, 1112, 1166, 1174, 1221, 1261, 1262, 1272, 1273, 1383, 1389, 1390, 1426, 1481, 1551, 1629, 1693, 1730, 1734, 1744

TABLE A-VI

Models, Modeling and Evaluation

Identification Submodel	62, 142, 206, 218, 565, 701, 1058, 1254, 1255, 1256, 1267, 1288, 1289, 1690
Recognition Submodel	19, 34, 35, 41, 40, 42, 43, 44, 45, 53, 56, 57, 64, 73, 76, 101, 102, 114, 115, 195, 138, 975, 984, 985, 1184, 1267, 1408, 1464, 1465, 1470, 1557, 1664, 1692, 1700
Detection Submodel	53, 56, 57, 121, 157, 156, 154, 158, 161, 168, 173, 174, 206, 342, 220, 224, 292, 293, 513, 565, 589, 616, 729, 827, 908, 909, 918, 963, 972, 984, 985, 1020, 1058, 1087, 1184, 1257, 1265, 1266, 1379, 1408, 1412, 1414, 1442, 1552, 1556, 1558, 1560, 1582, 1621, 1661, 1690, 1704
Search Submodel	23, 30, 57, 83, 84, 148, 150, 169, 170, 172, 173, 174, 177, 178, 179, 217, 223, 390, 394, 435, 503, 626, 720, 724, 797 920, 939, 940, 941, 952, 993, 1100, 1173, 1196, 1264, 1309, 1310, 1311, 1312, 1337, 1465, 1479, 1581, 1585, 1641, 1642, 1676, 1677, 1678, 1703, 1705, 1710, 1738
Atmospheric Model	20, 21, 25, 32, 36, 58, 147, 185, 186, 188, 187, 189, 207, 208, 219, 457, 1095, 1097, 1184, 1293, 1329, 1348, 1408, 1612, 1617, 1623, 1638
Terrain Submodel	79, 81, 827, 1379, 1516, 1652
Mission Parameters	529, 790, 823, 923, 924, 947, 1079, 1089, 1128, 1250, 1286, 1323, 1426, 1429, 1468, 1527, 1590, 1616, 1622, 1662, 1698

Validation Data - Flight	3, 15, 24, 28, 31, 33, 37, 55, 78, 80, 93, 94, 122, 166, 169,170, 193, 216, 249, 254, 346, 394, 441, 502, 513, 523, 611, 632, 719, 723, 725, 731, 733, 735, 812, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 871, 880, 881, 1131, 1182, 1183, 1251, 1370, 1453, 1520, 1566, 1593, 1600, 1615, 1684, 1685, 1686, 1687, 1688, 1689, 1692, 1731
Navigational	46, 47, 192, 193, 727, 730, 1000, 1015, 1105, 1106, 1107, 1108, 1109, 1110, 1218, 1261, 1262, 1277, 1282, 1383, 1546, 1594, 1659, 1701, 1702, 1730
Sensor Submodels	14, 2, 48, 51, 53, 54, 67, 70, 69, 71, 88, 100, 101, 102, 122, 124, 133, 135, 140, 172, 198, 375, 487, 866, 976, 988, 989, 1068, 1123, 1125, 1166, 1175, 1177, 1184, 1288, 1289, 1290, 1408, 1431, 1432, 1502, 1506, 1509, 1510, 1511, 1512, 1522, 1532, 1714, 1721
Operator Submodel (Psychophysical)	22, 182, 252, 253, 944, 1003, 1290, 1305, 1352, 1379, 1400, 1401, 1408, 1414, 1462, 1535
Inherent Contrast	1194
Training	5, 141
Johnson Criterion	142, 200, 841, 840, 843
Multi-Spectral	18, 181, 257, 277, 649
Multi-Sensor - Multi-Display	305, 425, 473, 687, 866, 1288, 1289, 1408, 1476, 1503, 1533
Multi-Target	1210, 1625, 1662, 767, 890
Clutter Variable	29, 64, 73, 160
Validation Data - Simulator	38, 166, 180, 525, 526, 651, 652, 656, 659, 1102, 1326, 1416, 1417, 1431, 1456, 1463, 1467, 1501, 1502, 1503, 1506, 1509, 1510, 1511, 1512, 1513, 1515, 1517, 1518, 1602, 1624, 1638, 1662, 1731, 1732, 1733, 1734, 1735
Weather Submodel	39, 816, 1408

Cueing Variable	18
Motion	27, 650, 1071
Resolution Sensitive	63
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GLOSSARY

The following definitions are pertinent target acquisition terms as used in this source book. Three primary sources were used to develop this glossary of terms:

(1) U.S. Joint Chiefs of Staff Publication 1 - Department of Defense Dictionary of Military and Associated Terms, (use is mandatory by Department of Defense Directive 5000.9).

(2) U.S. Joint Test Project Plan of Combat Air Support Target Acquisition Program SEEKVAL, July 1973.

(3) Definitions developed by the authors.

ACQUISITION - The process of detection, recognition and/or identification of a target in sufficient detail to permit the effective employment of a weapon against a target. A generic term covering all aspects of targeting.

ACQUISITION, AIDED VISUAL - Acquisition by means of direct-viewing optical devices or by means of devices that present target information to an observer on a separate display.

ACQUISITION, DIRECT VISUAL - Acquisition by use of the unaided eye.

ACQUISITION SYSTEM - A system that assists an observer in one or more of the target acquisition tasks of detection, identification, or localization.

ACUITY-VISUAL - In general, the ability of the eye to see fine detail. At least five types are of interest in target acquisition.

a. Minimum visible refers to the ability to see a point source of light. It is a function of intensity.

b. Minimum perceptible, also called spot detection, is the ability to see small objects against a plain background. Size, brightness, and contrast are determining factors.

c. Minimum separable, also called gap resolution, refers to the ability to see objects as separate when they are close together.

d. Vernier is the ability to recognize that two lines drawn end to end are slightly offset from each other.

e. Stereoscopic is the primary binocular ability of the eyes to determine which of two objects is closer; also called depth perception.

ALBEDO - The fraction of the incident energy which is reflected by an object in the entire spectrum from the ultra-violet to the far infra-red.

ANGULAR SUBTENSE - Angle subtended by an object at the observer's eye or sensor's optics.

ATTENUATION - Decrease in intensity of a signal, beam, or wave as a result of absorption of energy and of scattering out of the field of view of a detector, but not including the reduction due to geometric spreading.

BRIGHTNESS - The perceived intensity of light; the sensation as distinguished from the photometric quantity, luminance. See also LUMINANCE, LUMINOSITY, and ILLUMINANCE.

CAMOUFLAGE - Use of concealment and disguise to minimize the possibility of detection and/or identification of troops, materiel, equipment, and installations. It includes taking advantage of the natural environment as well as the application of natural and artificial material.

CHROMATICITY DIAGRAM - A diagram on which the color of an object may be specified in terms of the relative amounts of its constituent primary colors.

CLOSE AIR SUPPORT - Air attacks against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces.

CLUTTER - Objects, natural or artificial in the general area of the target other than the target which tend to hinder target acquisition because of their perceived similarity to the target.

COLOR CONTRAST - A difference in color between the target and its background, which may be obtained from a chromaticity diagram having experimentally determined contours of equivalent contrast.

COMBAT AIR SUPPORT - Air attacks against hostile targets that are in close proximity to friendly forces or against more remote targets on the battlefield that can contribute to the outcome of a battle; does not include interdiction.

CONCEALMENT - Protection of a target from observation.

CONES - The receptors for the optic nerve, located in the retina and concentrated in the fovea and macula, which are concerned with sharp vision, high ambient light, and color vision. See also RODS.

CONTRAST, APPARENT - For a given range, the difference between the luminance of a target and the luminance of the background, divided by the luminance of the background; includes the effects of atmospheric attenuation.

CONTRAST, INHERENT - For luminance measurements taken close to the target (to avoid the effects of attenuation by the atmosphere), the difference between the luminance of a target and the luminance of its background, divided by the background luminance.

CRITICAL FUSION FREQUENCY - The rate of presentation of successive light stimuli which is necessary to produce complete fusion and to have the effect of continuous illumination, sometimes called critical flicker frequency.

CUE - An item, feature, or signal that enhances target detection or acts as an indication of the nature of the object perceived.

CUEING DEVICE - A device that receives and displays cues to an observer.

DETECTION - The determination that an object classifiable as a target has been seen, i.e., the decision that a possible target is present in the scene being searched.

DIFFRACTION - A modification of light, which occurs when the light passes by the edge of an opaque body or through narrow slits, in which the rays appear to be deflected, producing fringes of parallel light and dark or colored bands.

DYNAMIC RANGE - The portion of the electro-magnetic spectrum over which a sensor can sense energy.

ELECTRO-OPTICAL SENSOR - A detector of electromagnetic energy that senses radiation from in the ultra-violet, thru the visible and infra-red region of the electromagnetic spectrum.

EMISSIVITY - The emissive power of a radiating surface expressed as a fraction of that of a black-body surface at the same temperature.

EXTINCTION COEFFICIENT - The sum of the absorption coefficient and the scattering coefficient for a medium that both absorbs and scatters radiation.

FLIGHT PROFILE - The flight path, airspeed, and altitude of an aircraft as a function of time.

FLIR - Forward Looking Infra-Red, an acquisition system originally designed to look forward from an aircraft, that senses radiation in either the 3 to 5 or 8 to 14 micron wavelength region of the electromagnetic spectrum and converts the scene into a visible display.

FOVEA - The retinal region of the eye that contains only cones; it is the area (approximately 1.5 degrees) that mediates the highest degree of visual acuity.

GAIN - The ratio of an obtained signal size to its input amount, i.e., the ratio of output amplitude to input amplitude.

GAMMA - The system luminance transfer function of a CRT display; the relationship between the input scene gray scale characteristics and the corresponding displayed gray scale.

GLARE - Any brightness within the field of vision of such character as to cause discomfort, annoyance, interference with vision, or eye fatigue.

a. Direct - Glare caused by a light source in the visual field.

b. Specular - Reflected concentrated light as distinguished from diffused light; caused by reflecting bright surfaces.

GLINT - A bright flash of light reflected from the target.

GROUND ILLUMINATION - The luminous flux falling on a unit area of the ground from the sun, sky, moon, etc.; expressed in lumens per square meter.

HEADS UP DISPLAY (HUD) - A display which is projected onto a normal combining glass to provide a pilot with flight, weapon system, or targeting information.

ILLUMINANCE - The total light flux incident to an area or surface.

LASER DESIGNATOR - A device capable of marking a target with a laser spot once the target has been acquired.

LASER SEEKER - An acquisition system capable of detecting a laser spot; not used in this book to refer to weapon-mounted seekers.

LIMINAL DETECTION - Detection under conditions where the probability of success is 0.50.

LOW LIGHT LEVEL TV (LLLTV) - A sensing system that responds to low intensity radiation in the visible region of the electromagnetic spectrum and electronically amplifies that radiation so that it is visible on a CRT.

LUMINANCE - The photometric term corresponding to radiance; specifies the amount of luminous flux radiated from an extended body per solid angle and per projected area of radiating surface; expressed in lumens per steradian per square meter.

MASKING - The concealment or partial concealment of a target from view. Targets are masked by natural or artificial features.

MICRODENSITOMETER - An instrument for measuring the optical density of very small areas of photographic film, or any other material.

MODULATION TRANSFER FUNCTION - A characterization of an acquisition system in the spatial frequency domain - - specifically, the magnitude of the Fourier Transform of the line spread function (the line spread function describes the display output of an acquisition system viewing an extremely narrow straight line).

MODULATION TRANSFER FUNCTION AREA - The area between the modulation transfer function curve of an acquisition system and the threshold-of-detectability curve of an observer.

MULTISPECTRAL SENSOR - An acquisition system that senses radiation in two or more regions of the electromagnetic spectrum.

NADIR - A point of ground reference located directly below the centroid of the aircraft.

NANOMETER - A unit of measure corresponding to 1 X 10^{-9} meters. Formerly termed millimicron.

NAP-OF-THE-EARTH FLIGHT - Flight performed as close to the earth's surface as vegetation and obstacles will permit and generally following the contours of the earth. Airspeed and altitude are varied as influenced by the terrain, weather and the enemy situation.

NEAR REAL-TIME - An information processing technique in which sensor data are processed and displayed with a time lag between sensor input and display.

NEPHELOMETER - An instrument that estimates the atmospheric extinction coefficient by shining a light through a sample of air and measuring the total amount of scattered light.

OBSERVER - One who acquires and designates targets; includes forward ground observers, aeroscouts, forward air controllers, and other aircraft crew members.

OCCULOMETER - An instrument that tracks the movement of an observer's eye.

OFFSET - The cross-range distance of a target from the aircraft flight path.

PARAFOVEAL VISION - Peripheral vision.

PATH LUMINANCE - The amount of luminous flux scattered into the line of sight of an observer.

PERCEPTUAL EMBEDDEDNESS - The degree to which a target appears to be part of a larger area, either background or foreground, thus providing a pattern which is difficult to detect or recognize as a target.

PHOTOMETER - An instrument that measures radiation in the visible spectrum.

PHOTOPIC VISION - Vision mediated by the cone system of receptors.

POP-UP MANEUVER - A flight maneuver in which the aircraft moves vertically from defilade to an unmasked condition, then returns to defilade. This maneuver may be performed with or without forward airspeed.

PSEUDOTARGET - An object or image that might be mistaken for the true target; a group of pseudotargets appearing in a scene constitutes a form of clutter.

PYRANOMETER - An instrument which measures sun and sky radiation giving the surface illumination.

PYRHELIOMETER - An instrument which measures the radiation from the sun.

RADIANCE - The radiometric term specifying the amount of power radiated from an extended body per solid angle and per projected area of radiating surface; expressed in watts per steradian per square meter.

RASTER - A TV or linescanner method of constituting a scene by painting successive lines on a CRT, i.e., the characteristics of such a sampled scene or the lines themselves when combined into a picture due to the ability of the tube to retain illumination by fluorescence.

REAL-TIME - Sensing, data processing, and display of information that occurs essentially at the time the event occurs.

RECOGNITION - The decision that an object detected can be specified as a particular object or member of a particular class of objects.

REFLECTANCE - The ratio of the flux reflected from a surface to the total flux incident upon that surface; varies according to the wavelength of the incident light.

RESOLUTION - A measure of the smallest detail that a system can discriminate; often expressed as an angle in milliradians or minutes of arc.

RETINA - The innermost coat of the back part of the eyeball, consisting of cells sensitive to light.

ROD - A light sensitive cell in the retina and concentrated on the periphery of the fovea. It is the only photoreceptor functioning under low levels of illumination.

SCOTOPIC VISION - Vision mediated by the rod system of receptors; "Night" vision.

SEEABILITY - The distance (slant range) at which a sensor (e.g., human eye, photometer, radiometer, photograph, TV camera, etc.) is able to see (recognize or lock onto) a target through the intervening atmosphere which may contain clouds, haze, smoke, fog, precipitation, or dust.

SIGNAL-TO-NOISE RATIO - The ratio of the peak-to-peak amplitude of a signal to the rms amplitude of the noise superimposed on the signal.

SKY-GROUND LUMINANCE RATIO - The ratio of the luminance of the sky to the luminance of the ground.

SKY LUMINANCE - The luminance of the sky at the horizon as measured in the same direction as the observer's line of sight.

SLANT RANGE - The range from the observer directly to the target along the line of sight.

SLANT RANGE OF VISIBILITY - The slant range for which the contrast between an object and its surrounding is equal to the threshold contrast of the human eye.

SNR_D - The actual signal to noise that is displayed on the face of a CRT; it includes the inherent SNR of the system plus that noise added by the characteristics of the CRT.

SPECTRAL SIGNATURE - The unique radiation of a specific object by which it may be possible to classify the object as a target or nontarget.

SUN ANGLE - The angle between the line from the sun to the target and the line from the target to the observer or also with respect to the horizon and true north.

THRESHOLD - The amount of signal required to cause a sensor to respond to that signal. In psychophysics, a probabilistic concept often defined as the amount of energy required for a subject to detect a stimulus on 50 percent of the trials.

TRANSMITTANCE - A factor less than one, describing the amount of light from an object that is transmitted through the atmosphere (i.e., not scattered or absorbed).

TURBIDITY - A coefficient which gives the total extinction of solar radiation by haze in a vertical column through the atmosphere.

VISUAL ANGLE - The angle subtended by an object in the visual field at the nodal point of the eye. This angle determines the size of the image on the retina.

END